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USSR: Engineering & Equipment

FOUNDRY INDUSTRY INDUSTRIAL ROBOTS

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SCIENCE & TECHNOLOGY

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FOUNDRY INDUSTRY INDUSTRIAL ROBOTS

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[Book by V. V. Serebryakov and A. M. Nadezhin, Izdatelstvo "Vysshaya shkola", 9,500 copies, 80 pages]

CONTENTS

[Text] Introduction

Much attention is devoted in the Basic Directions for the Economic and Social Development of the USSR for 1986-1990 and up to 2000, confirmed by the 27th CPSU Congress, to automation of manufacturing processes to increase productivity and for a significant reduction of the fraction of manual labor in industry. These propositions are also totally true of the foundry industry, which, being the main billet base of machine building, still contains a considerable fraction of manual labor. Specific operations are frequently performed manually even on automated sections. This is ordinarily dull, monotonous and exhaustive labor that requires intensive exertion (for example, placing cores into molds on a conveyer).

The prospects for automation of the foundry industry are based on introduction of flexible manufacturing systems, capable of rapid readjustment upon transition to output of new types of castings. In turn, flexible manufacturing systems (GPS) should be supplied with equipment which would ensure high productivity. Industrial robots (PR), among the characteristic features of which are multiple reprogramming to perform various types of jobs and flexibility and adaptability to different production conditions, fully correspond to these requirements.

Robots are used in pressure die casting and in casting by the lost-wax process, in airless shot-blasting operations and in operations of cleaning castings for control of the cleaning tools and of casting during machining. There are broad opportunities to introduce robots in metal transportation operations and in operations of pouring metal into molds. The robot is the pouring apparatus in this case. When servicing the iron mold, the robot can remove the casting from the mold, can transfer it to the cooling conveyer, and can place cores in the iron mold. Robots equipped with a viewing system can be used in placing the cores in the mold and in knock-out of castings from the molds.

Introduction of robots is related not only to specific expenditures, but to considerable preparation that ensures variation of the process flow diagrams, redeployment of equipment, correction of the design of molds and of pouring systems, and refining the organizational structure of the shop and of the composition of workers.

Besides a significant reduction of the total manpower, the use of robotized systems permits a reduction of the length of the manufacturing cycle of producing castings to a practical minimum, which comprises 5 hr for average nonheat-treated castings. The areas occupied by intermediate warehouses, and the quality of castings is enhanced. Moreover, the use of robots considerably increases labor productivity in foundries, increases the fraction of mental labor of foundry workers, and makes their specialty even more prestigious and interesting, which in turn ensures a rather large influx of youth, looking for creative labor, into the foundry industry.

1. Industrial Robots and Manipulators

1.1. Classification of Industrial Robots

The existing designs of robots can be divided into three classes: domestic, information, and industrial. Domestic robots have not become widespread due to their limited capabilities to do useful work. Information robots are used in performing jobs under extreme conditions. These robots have been improved significantly. They include moon rovers, robots for study of marine depths and so on. Industrial robots are designed to replace the physical labor of man. These robots include 85-90 percent of the world's stock of robots.

An industrial robot is an automatic machine, stationary or mobile, consisting of an actuating device in the form of a manipulator, having several degrees of mobility, and a programmed control device.

All industrial robots, regardless of their designation, can be divided into three types according to the degree of their universality: universal, specialized and special. Universal robots are capable of solving various types of manufacturing tasks, of performing different operations, and of maintaining various types of equipment. Structurally, these robots are essentially independent of the type of production equipment, for maintenance of which they were designed. Specialized robots have a narrower designation and are used to perform similar operations of the manufacturing process and to maintain specific types of equipment. Special robots are designed to perform a specific manufacturing operation (for example, they service a specific model of production equipment).

Industrial robots are divided according to their type of manufacturing operations to be performed into those that perform auxiliary operations in maintenance of production equipment (auxiliary industrial robots) and into those that perform the main manufacturing operations (main industrial robots). The main robots are ordinarily related to the main production equipment, while auxiliary robots are related to automation equipment. This classification of industrial robots can be defined as classification according to designation. Moreover, industrial robots can be classified according to indicators that determine their design: by the type of drive (electric, hydraulic, pneumatic, and combination), by the load capacity of the manipulators, by the number of manipulators, by the type and parameters of the operating zone of the manipulators (region of surrounding space, within which the robot can perform its manipulations without moving), and according to mobility and the method of positioning (mobile and stationary and also floor and suspended).

Industrial robots are divided according to the method of control into programmable, adaptive and intelligent. Control according to individual degrees of mobility can be continuous (contour) and discrete (position). In discrete control, motion is achieved according to a given finite sequence of points by steps from point to point without assignment and checking of the parameters of the trajectory of motion between these points. A simpler variant of position (discrete) control is cyclic, in which there are a minimum number of positioning points for each degree of mobility.

An important parameter of the robot control system that determines their operating capabilities is the memory capacity of the controller and the form of communications.

The speed and accuracy of movements are the next criterion of industrial robot classification. These parameters are closely related to each other and characterize the dynamic properties of robots. Industrial robots are divided by speed and accuracy of movements into low-speed robots (linear speed up to 0.5 m/s according to individual degrees of mobility), medium-speed (from 0.5 to 1 m/s), and high-speed (more than 1 m/s) robots. The accuracy of the manipulator is characterized by the resulting positioning error or by the accuracy of covering a given motion trajectory. General-purpose industrial robots are divided into three groups according to accuracy of motion: low accuracy (with linear error from 1 mm or more), medium accuracy (from 0.1 to 1.0 mm), and high accuracy (less than 0.1 mm).

Approximately 80 percent of the total stock of industrial robots are now medium-speed and only 20 percent are high-speed. Most industrial robots have medium positioning accuracy.

The above classification features of robots are used to formulate the type of robots and accordingly to name them (for example, a light pneumatic industrial robot with cyclic control for maintenance of pressure die casting machines). Industrial robots, used in the foundry industry, frequently have pneumatic, electric and even hydraulic drives. These robots are mostly fixed, mobile or floor-mounted with individual control console. The positioning accuracy may be ±10 mm (sometimes higher). They have a load capacity up to 3,000 kg. They should be highly heat resistant and should have dust protection. The sphere of influence of industrial robots is being expanded continuously and the list of types of robots that define their designation is accordingly increasing.

1.2. Functional Diagram of Industrial Robots

The functional diagram of an industrial robot (Figure 1.1) indicates the relationship and interaction of its individual modules 1-12 during operation. Individual modules or groups of modules comprise the components of the robot that perform one or another functions. A robot generally consists of a motive (or motor), control (or intelligent), and

information (or sensory) systems. Robots are divided into generations as a function of the degree of perfection of these systems.

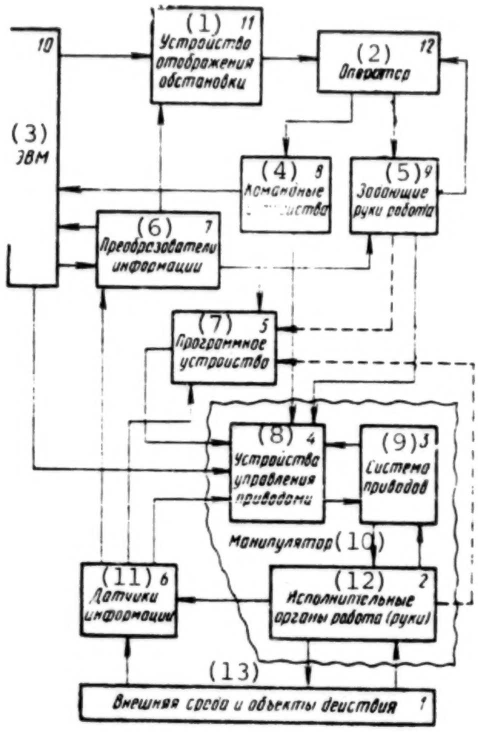

Figure 1.1. Functional Diagram of Varieties of Robots

KEY:

1. Position imaging device
2. Operator
3. Computer
4. Command devices
5. Master arms of robot
6. Information converters
7. Programmer
8. Drive controller
9. Drive system
10. Manipulator
11. Information sensors
12. Actuating members of robot (arms)
13. External environment and objects of action

The motive system determines the dynamic properties of the robot and its capability of performing different motions. The instructions coming from the controller are performed by using the motive system. Various types of drives and connected manipulators (mechanical arms) and also elements that move the robots are used as the structural elements of this system.

The control system is the unique "brain" of the robot. The law of control of the drives of the actuating members is generated through the control system. The robot communicates with the operator at a specific communication step through the control system and the control system is

used to plan the actions and to make decisions. The control system of a modern industrial robot is ordinarily based on a computer or microprocessors.

The information system is artificial robot sense organs, which, like human sense organs, perceive and transform information about the status of the external environment and of the robot itself into signals that are fed to the control system.

The industrial robot communication system exchanges information between the operator and the robot, between a given robot and other robots, between the robot and production equipment, and also between individual elements of the robot itself.

Modules 2, 3, and 4 in the functional diagram (see Figure 1.1) are the motive system--the manipulator which the robot used to act on the external environment (module 1) in which it is located and on the object of action. The external environment characterizes the conditions in which the actuating members of the robot act. Objects which the robot should manipulate or which it should detour as an obstacle in a given direction of motion of the actuating members are located here.

The drive controllers (module 4) are only the lowest degree of control of the drive system, switching them on and off and changing them. The drive controllers respond either upon instruction of the programmer (module 5) or from the instruction device (module 8), controlled by the operator (module 12). Robots can thus work with man or be completely automatic. The latter may have different degree of independence and are divided as a function of this into three generations. One should bear in mind that the robots of each generation are designed to perform their own tasks and do not serve to replace each other. All three generations of robots can be used in industry.

First-generation robots include the manipulator (modules 2, 3, 4) and programmer (module 5). This robot operates according to a strict program in a previously assigned environment and with strictly oriented objects. The programmer can be readjusted to perform a different type of operations, but again according to a strict program. A series of these programs can be entered in the programmer, but the version which each new program is assigned during teaching can be used. The robot is taught by different methods, including those using instruction devices (module 8), on which the operator acts (module 12). The simplicity of changing the program (reprogramming) of first- generation robots when switching to new operations would make these robots rather universal with the possibility of flexible readjustment within the functional capabilities of a given robot. These robots can be used in FMS (flexible manufacturing systems) with numerical control for servicing different types of equipment and including pressure die casting machines, in assembly of the casting mold for placement of cores in the mold and so on. However, the functional capabilities of first-generation robots are considerably limited due to the insignificant

variety of sensors (sensing elements) and due to the very imperfect control system. First-generation robots essentially do not perceive the situation in the work zone and, operating according to a strict program, pay no attention to random variations of conditions in the environment. Teaching these robots and sometimes operation of them require operator interference. They are used only under fixed conditions.

Second generation robots (adaptive robots) have sensing elements in the form of different sensors (module 6) that transmit information about the status of the robot arm and about the objects which the robot should manipulate. Moreover, sensors that report about the main necessary properties of the environment in which the process is occurring can be installed. Contact sensors that respond when the robot arm touches an object, location sensors that determine the speed of motion and distance to objects, television and optical sensors that form an artificial image, force and moment sensors on the actuating arms of the robot, and also sensors capable of distinguishing color, heat, sound and so on can be used as the sensors of an adaptive robot. The sensor system (module 6, see Figure 1.1) ensures feedback between the environment and the robot. The sensor signals that reflect the status of the external environment are fed to the program (module 5) to shape the control signals transmitted to the drives of the actuating devices (modules 4, 3, 2). As a result of this communication, the robot begins to act with regard to the actual situation, i.e., it adapts to a real existing situation. Depending on the type of sensors and on their number, different sensing versions can be developed with respect to the tasks faced by the robots in one or another environment. These sensitive robots can operate in a partially variable environment. Programs of typical actions which are included automatically as a function of the situation are preloaded into the programmer or computer. Thus, the second-generation robot control system does not reduce to development of a device for storing a rigid program of motions, like first-generation robots. The robot realizes the control program through a microcomputer. A signal is fed to the computer from the sensors through an information converter (module 7) and is processed in the computer with regard to the manufacturing situation. Synthesis of this control law reduces to shaping communications of the class of situations-action type. Each such communication is either previously placed in the memory of the control system or is formulated during teaching of the robot. Control according to the indicated type of communication is similar to the response of conditioned reflexes in living matter. The robot's behavior is said to be reflexive. An inseparable part of second-generation robots is their software, which realizes control. Because of the capability of perceiving the external situation, of analyzing information coming from the sensors, and of adapting to changing operating conditions, second-generation robots can manipulate unoriented and unordered parts, can perform assembly and installation operations, can collect information about obstacles in the work zone and so on.

Third-generation robots (intelligent robots) have artificial intelligence. They have a high degree of sensing--perception and

pattern recognition or situation-perceiving devices, decision-making devices, and also devices for automatic planning and checking of operations to be performed as a function of the postulated problems and of the recognized situation. These robots, along with sensing, have a well-developed external information feedback system, which provides the robot with the capability of intelligent behavior, similar to man in a similar situation. Third-generation robots are controlled from a computer, which, receiving information from the information converter on the status of the external environment, from the robot itself and from the object of action, makes a decision on the further actions of the robot and issues an instruction to the drive controllers. The robot's behavior, depending on the existing situation, is thus assigned and affects the surrounding environment. However, regardless of how perfect the robot control system is, there most always exist feedback between the operator and object of action. This feedback can be achieved through the situation display (module 11), television communications or even through a viewing port. Accordingly, the functional system of a specific industrial robot is determined by the complexity of design of the control circuit and by the capabilities of the industrial robot adapting to the situation in the work zone. The higher the capability of the robot for independent work in performing a manufacturing process, the more complicated the system of sensors and feedback are and the more complicated the programmers are.

1.3. Specific Mechanisms of Industrial Robots

As indicated above, the robot as a whole is a machine consisting of actuating mechanisms and controllers. The actuating mechanisms contain one or several manipulators, supplied with specific accessories that permit the robot to perform the functions entrusted to it. The presence of manipulators in the robot is its characteristic feature that distinguishes the robot from other, even automatically controlled machines.

The mechanism for performing motive functions, similar to the functions of the human arm, when moving an object in space is called a manipulator. These devices can be used as individual human-controlled machines (manipulators with manual control) or can be the actuating members of industrial robots. Mechanical manipulators are now the main type of manipulators for robots. They are an open kinematic circuit, consisting of kinematic pairs that have one or several degrees of mobility with forward or angular movement of the working member, located on the end of the manipulator, and drives, frequently separate for each degree of mobility. Similar to human arms, manipulators have many degrees of mobility, which ensures a large number of variants of kinematic diagrams of the actuating arms of robots. All degrees of mobility of the manipulator should be controlled, while the functional diagram of the arm should ensure grasping at any point of the work zone and should ensure any required orientation of the gripping device at each point. At the same time, an increase of the number of degrees of mobility, expanding the robot's manipulation capabilities, results in

considerable complication of the design of the robot itself. Therefore, the number of degrees of mobility of the robot arm is determined by the nature of the operations to be performed.

The human arm has the capability of moving, of sensing force, of sensing temperature, of feeling pain and so on. The presence of a large number of functions makes the human arm a universal tool for active intervention on the environment. A manipulator naturally is incapable of fully copying the human arm. It has more limited capabilities. However, the manipulator can even now perform the functions of the human arm to a considerable degree, and sometimes can exceed it. Thus, individual manipulators have higher load capacity to overcome the force of gravity. Unlike the rest of the human arm, which has 14 degrees of mobility, a manipulator does not reproduce the motions of many joints of the fingers. At the same time, the manipulator has a telescopic extension of individual sections, or forward motion from a body, which the human arm does not have. Thus, a general view of the kinematic structure of the manipulator member is specifically related to the functional diagram of the human arm, but there is no clear uniqueness in this relationship.

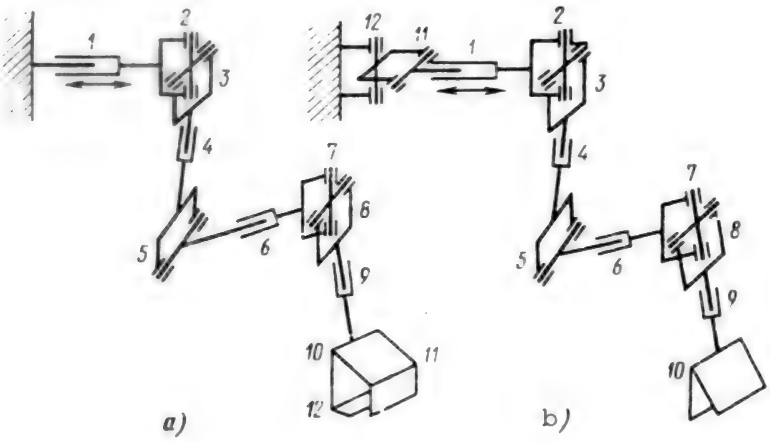

Figure 1.2. Functional Diagram of Robot "Arm" With 12 Degrees of Mobility

Two versions of the functional diagram of a robot's mechanical arm are presented in Figure 1.2. Each version has 12 degrees of mobility. Comparing the operation of joints in the given diagrams to the motion of the human arm, one can make a specific analogy. Joint 5 in both versions corresponds to rotation in the elbow joint. Links 7 and 8 are similar to the two degrees of rotation of the human wrist, while link 6 is similar to the rotation of the wrist with respect to the elbow (rotation of the forearm). Link 9 corresponds to rotation of the wrist and represents rotation of the gripping device. Link 10--opening of the gripping device--is similar to opening the palm of the hand. Link 4 is similar to rotation of the elbow with respect to the shoulder joint.

The joints of links 2 and 3 provide two degrees of rotation, similar to movement in the shoulder joint. Link 1 provides forward motion (extension) of the entire robot arm from its body. The human shoulder does not have this motion. The enumerated 10 motions are identical both in the version shown in Figure 1.2, a and in the version in Figure 1.2, b. The difference in the diagrams is that links 11 and 12 (rotations of the lower parts of the lips of the gripping device) operate similar to the finger joints in version a. And links 11 and 12 in version b operate similar to rotation of the trunk of a sitting person.

Besides the difference in distribution of the degrees of mobility between the human arm and the robot arm, there is a significant difference in the ratio of the geometric dimensions of the individual links. Selection of the version of the functional diagram is determined by a number of specific conditions. The diagram should ensure sufficient degree of functional universality of the robot with respect to the operating cycles in some external environment. At the same time, one attempts to provide the greatest simplicity of design of the arm, the technological efficiency of manufacturing it and the lowest cost. Besides these conditions, there are a number of specific requirements determined by the area of application of the robot.

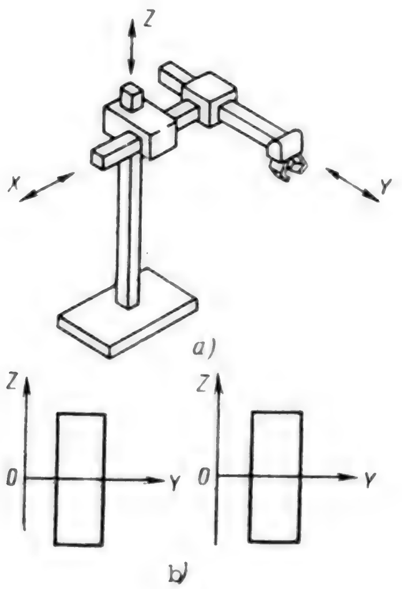

Figure 1.3. Manipulator With Rectangular Coordinate System (a) and Its Work Zone (b)

The diagram of a manipulator that performs movements in a rectangular coordinate system is presented in Figure 1.3, a. The robot arm can move in the vertical direction along the Z axis and in two mutually perpendicular directions along axes X and Y. The work zone serviced by this manipulator is shown in Figure 1.3, b. Only forward motions are

performed in this case. This coordinate system can be used successfully to perform linear motions. It simplifies considerably the programming of the robot.

Manipulators that operate in a cylindrical coordinate system (Figure 1.4), along with forward motion (axes R and H), have one other angular movement (along circumference φ). The work zone of this manipulator has the shape of a cylinder.

Manipulators that operate in a spherical coordinate system (Figure 1.5) have two angular displacements (θ, φ). The work zone of this manipulator assumes the shape of a sphere. Robots with this coordinate system are very compact, but are very complicated in design.

A manipulator may also have only angular movements (Figure 1.6). All the links of this manipulator are articulated. Manipulators of this type are said to be jointed. They can be assembled, essentially not going beyond the overall dimensions of the robot base. However, the control system of this manipulator is very complicated.

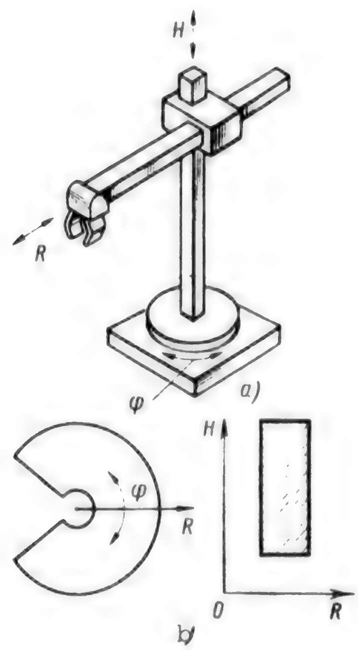

Figure 1.4. Manipulator With Cylindrical Coordinate System (a) and Its Work Zone (b)

The manipulators presented in Figures 1.3-1.6 have only three movable degrees of maneuverability each. However, in practice they have a greater number of links and therefore the number of their degrees of mobility is considerably higher. A manipulator ordinarily combines different combinations of the considered coordinate systems in different

combinations. Accordingly, a manipulator for a robot performing one or another manufacturing operation can now be selected.

Balanced manipulators, which have an angular coordinate system, are used to perform loading-unloading operations. The load in them is automatically balanced, due to which the load taken by the manipulator can be moved within the work zone essentially without application of force. One can consider as an example the ShBM-150 hinged balance beam manipulator with capacity of 150 kg (Figure 1.7). A drive head 3 with electric drive for rotation of link 4 in the vertical plane is mounted on a column 1 of a rotary device 2. Link 4 includes a pantograph, which maintains the vertical position of link 5 during rotations of link 4. A rotary head 6 with control level 7, clamp 8 and attached removable gripping device 9 are mounted on the end of the link 5. The lever system itself of the manipulator is balanced through a spring device, located in drive head 3. The operator controls the manipulator through handle 7. The direction of movement in the vertical plane corresponds to the direction of movement of handle 7, while the speed of movement is proportional to the angle of rotation of the handle. The load is stopped with the handle in the neutral position and is held in this position. The manipulator is moved in the horizontal plane due to the operator's muscular force. However, force is required only to overcome the forces of gravity and inertial.

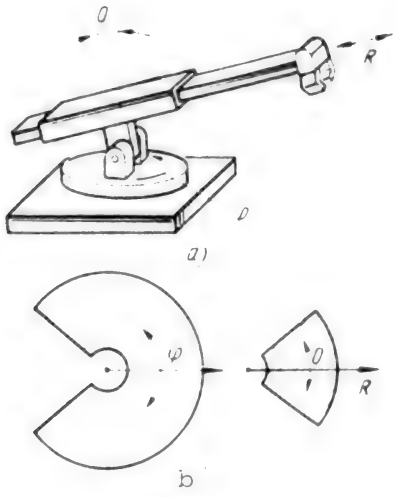

Figure 1.5. Manipulator With Spherical Coordinate System (a) and Its Work Zone (b)

The manipulators used in robots consist structurally of several working members; they provide direct interaction of the robot and objects of the external environment. These working members of the manipulator may include gripping device mechanisms, special tools and drives. Some working members of the manipulator can be supplied with sensing devices,

which considerably expands the capabilities of automatic control of robots.

Gripping mechanisms are usually connected to the last link of the manipulator. Their duties include grasping of an object, holding it during manipulation and lowering it at the end of the process. Gripping mechanisms can be mechanical, pneumatic, electromagnetic or may combine different combinations of the indicated elements. There may also be special gripping mechanisms, designed to perform specific operations of the manufacturing process. The gripping mechanisms of industrial robots should be replaced rapidly during readjustment of the robot and should ensure reliable gripping of parts, different in geometric dimensions and mass within limits provided by the parameters of the industrial robot. One of the most important assemblies of the gripping mechanism are the gripping devices.

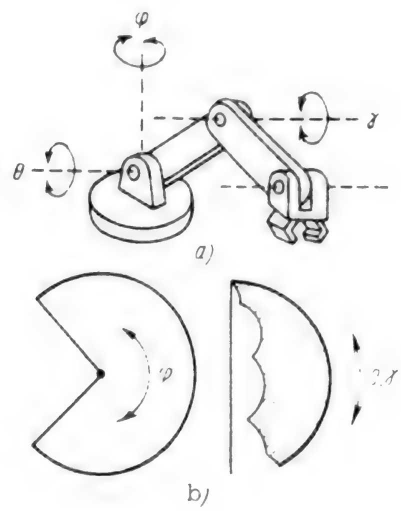

Figure 1.6. Manipulator With Angular Coordinate System (a) and Its Work Zone (b)

Gripping devices are similar to the wrist of the human arm. Two-finger gripping devices are simplest. They are similar to flat-nosed pliers having a drive. A similar device for gripping cylindrical articles along the outer surface and centering them is shown in Figure 1.8. Joints 3 that support different gripping jaws are mounted on the rod 1 of a pneumatic cylinder 2. Depending on the designation of the robot, the jaws can be permanant, quickly replaceable, and reinforced with rubber to increase their elasticity. They are supplied with sensing elements in the form of contact sensors, sliding sensors, force sensors (along one or several axes), remote sensors (ultrasonic, optical and so on), capable of determining the outside of objects near the gripping device and between its jaws. The inside surface of the gripping device can be covered with a grid of conducting elastomer with piezoelectric

properties. Electric pulses are generated in its assemblies in the case of the grid pressing against a hard surface. Such coating of the jaws, connected to a computer circuit, permits one not only to signal contact of the jaws against the object, but also to regulate the force of gripping.

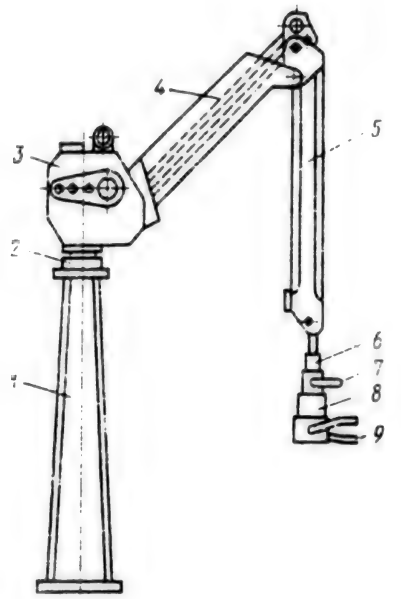

Figure 1.7. ShBM-150 Electromechanical Balanced Manipulator

A clamping mechanism can be provided with several gripping devices, which facilitates gripping and holding stepped articles along several different surfaces. The design of gripping jaws is determined by the configuration of the surface of the product to be clamped and by the requirements on moving it. Regulated self-centered gripping devices of two jaws with prismatic or cylindrical internal profiles are used for products with cylindrical outer surface. The jaws for gripping spherical products can be flat or can have a depression. In the latter case, the jaws are less universal, but less compressive force of the jaws is required for them to hold products. Divergent multiclamp gripping devices can be used to grasp products with internal cylindrical surface. Three-contact internal divergent gripping devices hold the load more reliably than four-contact ones. Gripping devices for products with flat surface have different working surface of the jaws. Two one-place gripping devices and one two-place device can be mounted on one lever of the manipulator. Elastic or force-distributing gripping devices are used to limit the clamping force. Removable foam plastic jaws or spring-loaded gripping devices with elastic clamps are attached to the clamping part of the gripping device.

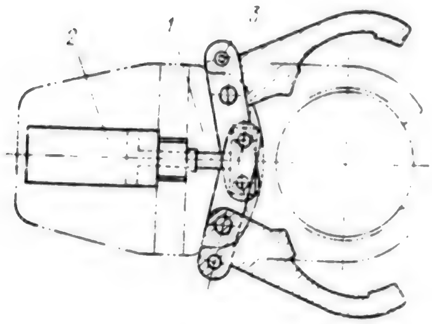

Figure 1.8. Two-Finger Gripping Device for Cylindrical Products

The design of a three-digit gripping device is shown in Figure 1.9. Each finger has three movable links each and can be rotated with respect to the longitudinal axis. The working principle of a pneumatic gripping device with five flexible inflatable fingers is presented in Figure 1.10. Air from a distributor is delivered along the channel inside the fingers. The fingers bend due to the different stiffness of the fingers through the cross-section under compressed air pressure, gripping objects in their zone of action.

Vacuum suction devices that hold the article due to a vacuum created upon suction of air from the cavity between the suction device and the article to be grabbed are used extensively in vacuum clamping mechanisms. The suction disks are usually made of rubber or plastics of different shape (Figure 1.11). Vacuum clamping mechanisms may have several suction disks to grap articles of complex shape. The advantages of vacuum clamping mechanisms are simplicity of design, low weight, uniform distribution of load along the surface of the product and self-centering. Vacuum gripping devices can be used for products of any dense materials. The surface of the products is not damaged. However, the operating life of these gripping devices is very low, especially with heated products. A vacuum is created in these gripping mechanisms by means of vacuum pumps. Suction disks can be attached to the gripping mechanism by screws or another method that ensures reliable strength. The pump is connected to the gripping devices either by an additional tube or by a hollow lever, connected to a vacuum system. To grasp products, a lever with suction disks is lowered to the product. The force of gravity ensures the necessary contact between the edges of the suction disk and the product to create a vacuum.

Magnetic gripping mechanisms are used for working with ferromagnetic products. Gripping mechanisms with electromagnets are mainly used in robots. One can also use permanent magnets, but in this case there must be a mechanical device (extruder) to separate the product from the gripping device for releasing the gripped product. Magnetic gripping mechanisms are similar to vacuum mechanisms in design. However, they

have a greater service life and greater speed. Moreover magnetic gripping devices have greater attractive force per unit surface area. Their disadvantages should include the impossibility of working with nonmagnetic products, which restricts their area of application, the presence of residual magnetism and the possibility of gripping foreign particles, which may damage the surface of the products to be grasped. The configuration, mass and area specifically influence the design of a magnetic gripping device (Figure 1.12).

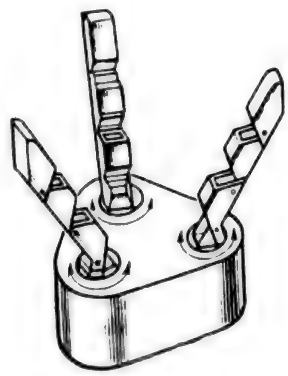

Figure 1.9. Gripping Device With Three Fingers

As indicated above, besides a gripping mechanism, a manipulator can be provided with special tools through which it performs the corresponding manufacturing operations (application of separating lubricant to the surface of the iron mold or press form, proportioning of the molten metal with it is poured into the mold and so on). This tool or accessory is attached directly to the manipulator. Delivery of some type of energy or working body (separating liquid) and so on to these accessories must sometimes be provided.

The working members of industrial robots most frequently move by electric, pneumatic, hydraulic and combination (electromechanical, pneumohydraulic and other) drives. The drives of a manipulator are arranged either on its base with transmission of motions to the corresponding link through some transfer mechanisms or in the links of the manipulator. Each of the indicated methods of arranging the drives has its own advantages and disadvantages. Locating the drives directly in the links of the manipulator considerably simplifies the functional diagram, which contributes to an increase of the operating accuracy of the robot. However, the weight and overall dimensions of the movable parts of the manipulator increase considerably and its load capacity is reduced. Combination arrangement of drives permits one to optimize the arrangement of the drives for different degrees of mobility.

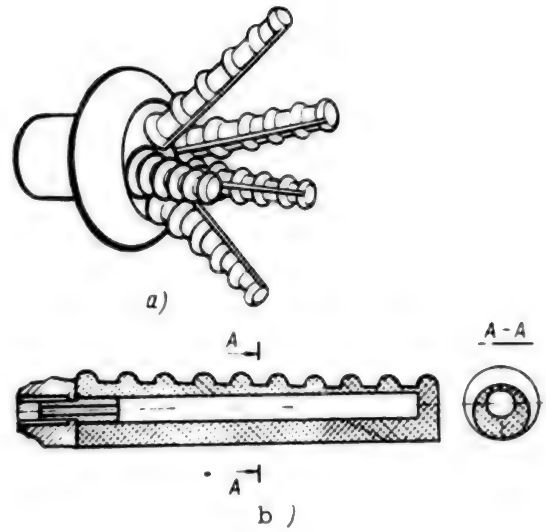

Figure 1.10. Pneumatic Gripping Device With Five Fingers (a) and Cross-Section of Finger (b)

In general form, the drive includes a motor and controller. It also includes different mechanisms for transfer of motion and for conversion of one type of motion to other types (for example, rotary and forward and vice versa). Moreover, the common drive includes a brake, clutches and so on. The motor should have small overall dimensions and weight, should be reliable, should have low cost, should be easy to operate, should operate under varying conditions with sharply variable load and so on. Moreover, high operating accuracy of the robot must be ensured.

Approximately 40 percent of the entire worldwide stock of robots goes to the fraction of those with pneumatic drives. Just as many robots have hydraulic drives. The fraction of robots with electric drives is 20 percent, but an increase of their fraction in the overall number is now being noted.

Broad distribution of robots with pneumatic drive is determined by the simplicity of design, low cost, speed and reliability. Pneumatic drives are more frequently used as unregulated drives with cyclic control. Industrial robots with pneumatic drive have comparatively small capacity (up to 10 kg and sometimes up to 20 kg).

A motor, distributor and governor are included in the pneumatic drive with one degree of mobility. The motor can perform forward motion (a pneumatic cylinder) and rotation (incomplete rotary motor). Pneumatic cylinders ordinarily have built-in brake that is triggered at the end of the piston stroke. Rotary pneumatic motors used in robots have a limited angle of rotation. There are also pneumatic rotary motors, consisting of pneumatic cylinders and a mechanical drive of the rack and pinion type, which converts forward motion of the rack to rotation of

the pinion. Pneumatic drives operate on compressed air at pressure of 0.3-0.6 MPa.

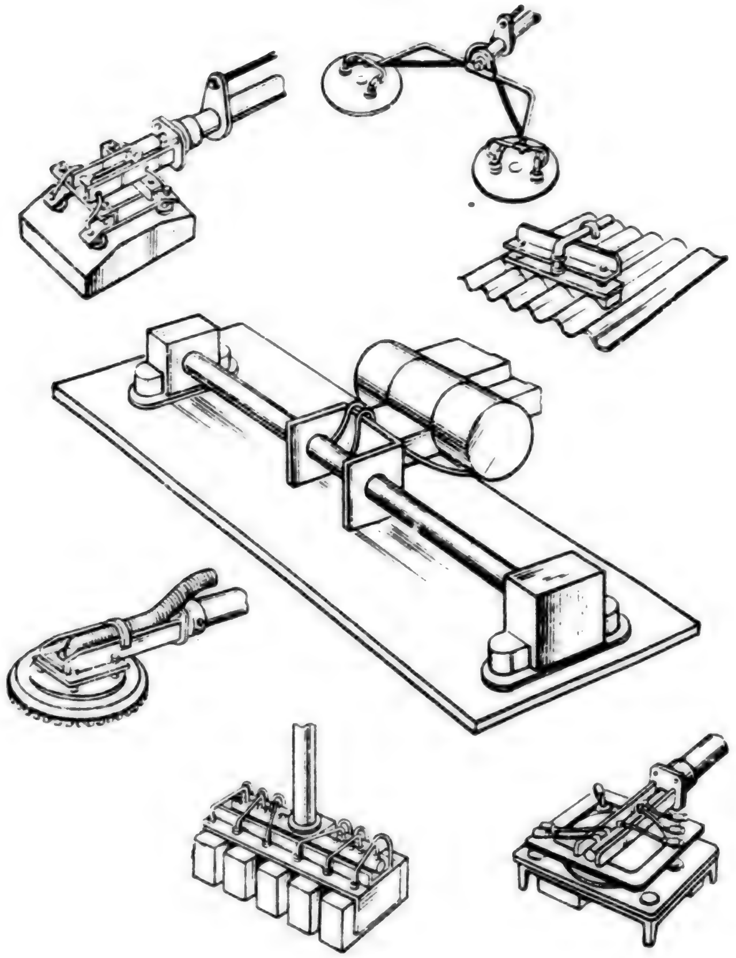

Figure 1.11. Vacuum Gripping Devices for Products of Different Shape

Distributors in the form of slides or valves, usually controlled by electromagnets, are designed to redistribute the delivery of air to pneumatic motors. Instructions to the electromagnets of air distributors are delivered from controllers.

The operating speed of a pneumatic drive is determined by the rate of delivery of air to the working cavity of the pneumatic motor. In turn, the rate of delivery is provided through different regulators (for example, chokes, reduction gear and so on).

Compressed air is delivered to the robot drives from a common pneumatic system and the following preparation occurs in the power supply module:

removal of moisture and mechanical impurities and also spraying oil to lubricate contiguous surfaces of the drive.

A diagram of a robot with pneumatic drive is shown in Figure 1.13. A rotary column 2 is mounted on a fixed bedframe 1. A hinged lever-gripping device is mounted on the column. Lever 4 is articulately connected to axle 3. A gripping device 5 with two jaws is mounted on the end of the lever. A pneumatic cylinder 6, the piston rods 7 of which is connected to lever 4, permits the lever to perform vertical forward-return motion. A stop 8, located on the lever, limits its upward motion. The lever-gripping device also has rotary motion in the horizontal plane.

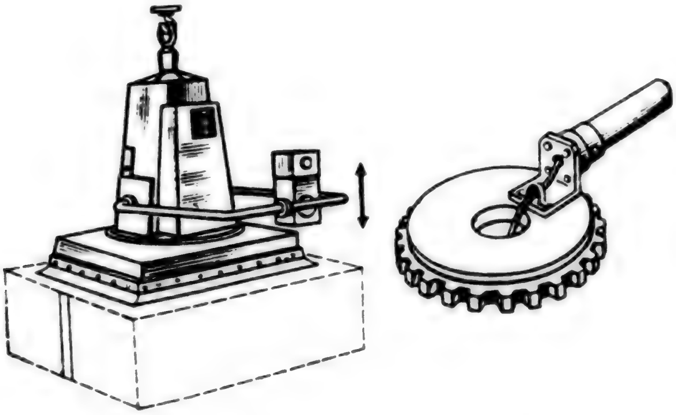

Figure 1.12. Magnetic Gripping Devices

Hydraulic drives are more complicated in design and have higher cost compared to pneumatic and electric drives. However, they have the best weight-size characteristics at considerable power (500 W or more) and are therefore widely used in heavy and superheavy robots. Moreover, hydraulic drives are easily controlled, which contributes to their use in robots of medium capacity, when high dynamic characteristics must be provided.

A hydraulic drive consists of the same main parts as a pneumatic drive. Its basis is a motor for forward (hydraulic cylinder) or angular (rotary hydraulic cylinder) motion, which are similar in design to pneumatic motors, but a liquid (oil or emulsion) under pressure up to 20 MPa is used in them instead of compressed air, which permits making the hydraulic drive structurally compact with large capacity. Unlike the pneumatic drive, where the spent air is exhausted to the atmosphere, the hydraulic drive has a second pipeline through which the spent liquid is returned to a tank.

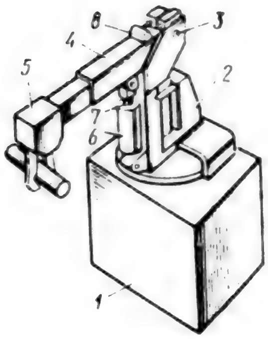

Figure 1.13. Robot With Pneumatic Drive

Hydraulic motors are controlled by slides and valves, which are ordinarily controlled electrically. A hydraulic drive has its own power supply included in the robot. This module includes a hydraulic pump, filters, pressure regulator, liquid cooling device and oil reserve storage tank.

The electric drive currently occupies a comparatively modest position in robot engineering, despite its easy controllability, simplicity of delivering power, considerably greater efficiency, and ease of operation. This is explained by the fact that the electric drive has poorer weight-size characteristics than pneumatic and hydraulic drives. However, progress in development of new types of electric motors, especially designed for robots, and the simplicity of controlling the electric drive ensure its broad use in robot engineering. The main part of the application is robots of medium capacity (tens of kilograms) and also lightweight robots.

DC, asynchronous and step motors, various types of regulated clutches in combination with unregulated asynchronous motor or a DC motor, electromagnets (solenoids) and so on are used in industrial robots. An electric drive with angular displacement is most frequently used. But since forward motions are also distributed in robots, along with electric drives based on rotating motors in combination with converters of the rack and pinion type, special DC and AC linear drives are used.

The electric drive generally includes an electric motor with position and speed feedback sensors, a mechanical gear, frequently a brake and sometimes a clutch (for example, to protect the motor against overload). Moreover, the electric drive contains a controller.

Combination drives permit one to use and combine the advantages of individual types of drives and also to compensate some disadvantages of them. The speed and final position of the piston rod of the pneumatic cylinder can be corrected with high accuracy in a combination pneumohydraulic drive using a hydraulic cylinder, installed parallel to the main pneumatic cylinder. There is no hydraulic pump station in the

hydropneumatic drive. This is provided by installing an ordinary pneumatic cylinder before the main actuating hydraulic cylinder. Low-power electric and output hydraulic drives are connected in series in hydroelectric drives. The input electric signal is converted by an electric drive to motion that serves as the input action for the hydraulic booster of the hydraulic drive.

Devices for moving mobile robots are also related to their actuating mechanisms. Floor-mounted moving devices, consisting of a running part and its drives, are mainly used. According to the operating principle of the running part, mobile devices are divided into wheeled, tracked, rail, those on electromagnetic suspension, air cushion, walking, creeping and so on. The path of the robot can be assigned by a magnetic tape or light-reflecting tape mounted on the floor. A robot moves above the tape and its position is monitored with respect to the tape by means of sensors. There are robots that move along a monorail track. The robot is positioned on the path by induction sensors. Robots used in foundries are frequently stationary and do not require devices for moving them.

2. Robot and Manipulator Control Systems

2.1. Classification of Control Systems

Control is understood as an automatic sequence of a combination of events, directed toward maintaining or improving the functioning of the controlled object according to the goal of control. The problem of control of industrial robots includes formulation of the control actions for the actuating members, through which the gripping mechanisms of the manipulator perform motions along a given trajectory with the required accuracy.

The following robot control systems and the corresponding controllers are distinguished:

programmed systems, in which control is achieved according to a previously compiled control program, which remains fixed during realization;

adaptive systems, in which the actuator of the industrial robot is controlled with automatic variation of the control program as a function of the parameters of state of the external environment to be checked;

intelligent systems, in which the adaptive properties are developed to a level corresponding to human intellectual activity.

Most modern industrial robots have programmed control. Three main types of control are distinguished: cyclic, position and contour.

Cyclic control is control of the actuating device of the industrial robot, in which the sequence of performing its motions is programmed. Cyclic control systems operate on end supports, upon contact with which a single motion of the working member of the industrial robot is switched to another motion according to a program. The robot can be easily and operationally readjusted through adjusting the stop switches and by changing the program that controls the sequence of motions.

Position control is control of the actuating device of the industrial robot, in which its working member moves along given positioning points without checking the trajectory of motion between them. Position control systems are discrete systems, where the position of a number of a number of points that define the given motion of the robot arm is programmed.

In contour control of an industrial robot, its working member moves along a given trajectory with established time distribution of speeds.

These systems are continuous control systems. They work out the trajectory of motion continuously for each of the degrees of mobility.

Different types of controllers (cyclic, position and contour) can be used to achieve different degrees of mobility in the same robot. Robots with cyclic control have high speed and rather high positioning accuracy. They are also used in foundries, for example, in maintenance of pressure die casting machines. Robots with position control are most frequently manufactured as universal robots and are used to maintain complex manufacturing operations, including operations performed in foundries. Contour-control robots are designed to perform very complex manufacturing operations.

Controllers can be individual, included in the composition of a single robot, or group, which control several robots. Structurally, individual controllers are made either separately from the mechanical part of the robot or in a common housing.

Most robots have electronic controllers, but there are nonelectric robot controllers (pneumatic and hydraulic).

2.2. Programmed Control System

The basis of programmed control is combination of the sequence of robot motions according to a previously calculated program. The program is stored in the memory of a computer and can be changed by reprogramming in a new robot teaching cycle (see section 2.5).

Most robots (approximately 70 percent) now have programmed control, which ensures broad use of them in a comparatively simple design version. A circuit that includes a number of devices that perform specific functions are used to achieve programmed control. The storage device contains the operating programs by which the priority of response of the robot working members is determined. Position controllers ensure development of given points and trajectories by the robot drives and of the equipment operating jointly with them. A transfer controller monitors the end of completion of the previous step of the program and transmits a signal to complete the next step. A timing device shapes the time delays required by the program in completing the next step of the program, and also the time delays between individual steps. All these devices are connected in the control circuit to sensitive elements (sensors) that signal the position of the manipulator and of its working members in space and also the communications with the robot drives, control console and external equipment.

The robot can operate in the programming mode or in the program reproduction mode. The first mode (programming) is essentially giving a task to the robot and teaching it. The second mode (program reproduction) is achieved by sending instructions to the actuating devices. The order of sending the instructions is determined by the reproduction principle imbedded in the controller. This can be achieved

either through a rigid sequence or with the possibility of changing the reproduction sequence according to some internal or external conditions. The internal conditions that cause the instruction reproduction sequence to be changed can be imbedded in the memory or can be assigned from the control console by an operator. Control according to internal conditions permits one to create additional functional capabilities (for example, to complete individual sections of a program many times).

Information about external conditions is fed to the controller in the form of signals about the course of some external process in which the robot participates. Depending on the signals received, the robot either switches to a different program during operation or omits individual sections of the program, or repeats them several times, or changes them and so on.

Signals about internal and external conditions are fed to the control module and alter the number of the next instruction to be processed. The operating principle of the control module is dependent on the principle of generating a signal about the end of the previous step and the readiness to begin completion of the next step. A signal can be generated through sensors, through a time relay, or through a combination system. Single operations are confirmed by the response of these sensors when they are controlled by signals. In time control, a signal about transition to complete the next step is transmitted by a timing device within a given time interval. A signal is delivered alternately from the sensor or the timing device with combination control.

2.3. Adaptive Control System

Adaptive control is based on the robot's skill in adapting to conditions of the external environment in which the manufacturing process is occurring. In other words, adaptive control is achieved as a function of environmental parameters and permits one to reach the goal of control with specific changes in this environment. To ensure adaptive control, the industrial robot should be provided with a sufficient number of sensory devices that perform the role of technical sense organs in the given case and that permit an increase of the operating accuracy of the industrial robot. Sensors transmit information to the processing system and to the system for synthesis of adaptive control laws. The presence of this control system permits the robot to function under different variable conditions. To solve these problems, the industrial robot should know how to fix the results of its own movements using the sensors and to estimate their correctness, and also to sense the surrounding situation, i.e., to compare its position and movement to that of objects external to it and to their movement. Information about the surrounding information comes in from devices which record the geometric, physical or chemical properties of the environment. The sensors of geometric properties limit the movement of the robot links as a result of the robot's touching or contact with objects located in the external environment. These sensors can be end switches, piezoelements

and so on. The sensors of the geometric properties also permit one to determine the distance to surrounding objects and the dimensions and orientation of the objects by location measurement methods (optical, ultrasonic, radiotechnical and so on). The sensors of physical properties permit one to measure forces, moment, density, pressure, temperature, color and odor. The sensors of chemical properties are entrusted with reporting data to the robot control system on the composition of the substances contained in the environment. One should bear in mind that the sensors transmit data in the form of currents, voltages, numbers and so on. To utilize these data to work out the control law, they must be processed by computer hardware. Previously compiled programs are used in adaptive control. Therefore, both program control and functions from current data about the environment are generally used in adaptive control systems.

Figure 2.1. Diagram of Sensitive Gripping Device of Adaptive Robot

An example of a manipulator that is sensitive using different types of sensors may be the MN-1 manipulator (United States), which has been named "Ernst's Hand" (Figure 2.1). The sensing elements of the manipulator include a switch 1, which closes when it comes into contact with an article and which determines its position between the jaws, six contact sensors 2 that respond when the external surfaces of the jaws come into contact with the article, six pressure sensors 3 that determine the position of the grasped article and the degree of its compression, photodiodes 4 that react to dark objects, and pressure sensor 5 and 6. The manipulator solves individual logic problems, for example, it can search for an article.

2.4. Intelligent Control System

The need for intelligent control of robots arises from the requirements of increasing their operating accuracy under conditions of an indefinite or rapidly changing environment. Intelligent control robots include those in which automatic decision-making on further actions of the manipulators is made according to the enlarged goal of the manufacturing operation. Intelligent control is the next, more perfected phase of control compared to adaptive control. An intelligent type of control is now in the development stage.

Those conditions when the incoming information will be insufficient and the situation varies according to a different given scheme may occur in practice. An industrial robot with an intelligent control system should find the correct solution and act so as to complete the manufacturing process more correctly. Artificial intelligence is realized in the control system of the industrial robot using computers. Solution of specific types of problems is undertaken if there is artificial intelligence. The level of the software system rises as experience is accumulated in solution of these problems and it becomes possible to develop self-improvement systems. There are as yet no serially manufactured industrial robots with intelligent control. There are robots with adaptive control and some elements of artificial intelligence.

2.5. Teaching of Robots

A robot is a taught system. The capabilities of robots to be taught are different. A complete robot, analyzing the status of the environment using sensing elements, formulates images of states and objects in the memory of the control system. Accumulating and transforming information, the robot can be taught by man or automatically skills and concepts and can also formulate in its memory a model of the surrounding environment. Because of this, it is able to perform operations which are linked to thinking in man (for example, pattern recognition, planning of behavior, decision-making, self-programming of motions and so on). The robot's control system must be supplied with the corresponding algorithms and software to perform these functions. The necessary information is fed to the robot in the form of teaching both by direct entry of it into the memory of the control system and by acting through the sensory system. The difference of the robot from the computer and automatons with rigid structure is that robots have the capability of being taught and of adaptation to conditions of the surrounding environment. If the programs realized on a computer reprocess only coded information, then robots, being in contact with the surrounding environment through the sensory system, can compare the actual state of the external environment and can act on it through their own actuating mechanisms. Teaching the robot is essentially programming its operation. This programming (teaching) is frequently performed when fulfilling a new cycle of movements of mobile devices for the first time in the manual control mode.

The robot teaching system is determined to a considerable degree by its functional capabilities. Thus first-generation robots, having a limited number of sensors, have a comparatively imperfect control system, which only fulfills a rigid program imbedded in the memory. In practice, these robots do not perceive the situation in the work zone. The robots are taught only manually by the operator in this case.

Second-generation robots have a considerable number of sensors and have a more perfected control system, which is capable not only of remembering a rigid program of motions but also of assigning these

motions, conforming to a specific degree to the conditions of the surrounding environment. These robots are provided with a microprocessor or microcomputer. Feedback signals for the control system, which, processing these signals, formulates the law of control of the actuating mechanisms of the robot according to the created situation, are formulated in second-generation robots using sensors. Synthesis of this control law, as already indicated, reduces to formulation of the contacts of the "class of situations-action" type. Each such contact is either previously embedded in the memory of the control system or is formulated during teaching of the robot by man. The presence of "class of situations-action" contacts permits the robot, although on a limited basis, to adapt to the existing situation.

The third generation of robots (intelligent robots) are distinguished to a considerable degree even from adaptive robots in the complexity of functions to be performed and in improvement of the control system. The control system of these robots itself already includes elements of artificial intelligence. A characteristic feature of robots with artificial intelligence is the capability of self-teaching on available experience during problems that arise. It follows from all the foregoing that teaching of robots is closely related to their control and can be achieved by different methods as a function of the complexity of the layout of the robot itself.

Teaching of a robot generally includes the control system remembering the required motions of the manipulator. These motions can initially be performed by man, teaching the robot manually. The program of these motions (their sequence) is stored by the robot and is retained in its memory. A program written in the memory is read from the memory during operation of the robot and is transmitted in the form of control signals to the actuating mechanisms. The robot manipulator performs the necessary motions according to the incoming signals, i.e., it processes the program.

A robot can be taught by different methods. The arm of the robot is moved upon a command supplied by the operator in direct teaching. This can be achieved by two methods: by moving manually the lever-gripping device of the robot during the cycle or by using a manual control gripping device. The first method is used directly for robots that perform a continuous process that does not require a high degree of accuracy. The memory fixes all movements and extreme and intermediate positions of the working members of the robot, after which the robot operates automatically according to a fixed program. Teaching is achieved by this method with the drive switched off (no pressure) during the teaching time. This ensures easy movement of the well-balanced arm of the robot. The lever-gripping device is also moved by the operator with the second method of direct teaching, but by using the manual control levers mounted on the wrist of the manipulator arm. Teaching is performed in the following order: the manual control levers are connected to the robot arm, a cassette containing a magnetic tape is installed in the control module, the selector switch is set to the

"Record" position, and the robot arm is set in motion by the manual control levers and moves to the positions required to perform the manufacturing process. The selector switch is then set to the "Playback" position; the manual control levers are removed and the robot is ready to perform the necessary manufacturing operation. The quality of teaching and the time expended on teaching are considerably dependent on the skills of the operator who teaches the robot. After the robot is taught, the cassette with the recorded program can be used repeatedly at any time. Only several seconds are required to change the program cassette. The tape with the recorded program should be rewound if there is multiple repetition of the same operation or of the same cycle.

A system can also be used when any of written programs can be arbitrarily selected and they can be reproduced in any sequence. The programs can be reproduced with variable sequence of instructions and with switching of them. The programs are usually selected during teaching, while they are switched according to signals of the sensing elements during reproduction.

The robot should be supplied with devices for positioning the working member in a necessary point of space with the required accuracy to ensure accurate completion of the program. The robot should receive information about the sequence of motions in the form of a combination of data on single actions in each of the sequential steps of the program and about the sequence of switching to the next step.

The program of motions of its lever-gripping device can be assigned by dialing it on a pin board, by using paper tape and punch cards or by recording on magnetic tape, on a magnetic drum and so on in direct (remote) teaching of the robot. The given program should also contain information about the sequence of motions and actions in each of the programmed steps, about the position (the numerical values of coordinates) of individual points at which the working member of the robot should arrive, and about the time which is needed to complete each sequential step of the program.

Information can be entered manually when teaching the robot (by resetting of cams, by dialing programs on a pin board and so on), semiautomatically (using paper tape and punch cards) or automatically (using a magnetic drum, magnetic tape and so on). Accordingly, a robot operating with playback of the recorded information (program) is taught by man. The sequence of motions is fixed in the memory of the robot control system and the manipulator then repeats these motions.

3. Use of Industrial Robots and Manipulators in Foundry Production

3.1. Use of Robots and Manipulators in Shops and in Pressure Die Casting Sections

Introduction of robotized manufacturing pressure die casting complexes is one of the basic directions in solution of the problem for a significant increase of labor productivity and improvement of working conditions in foundry production.

Automated pressure die casting complexes permit an average 22-30 percent increase of the productivity of the process, and approximately 60 percent of the achieved efficiency goes to automation of manipulator operations using industrial robots and manipulators. Proportioning and pouring of the melt from the bale-out pot furnace to the machine press chamber, the cycle of operations performed by the pressure die casting machine, including opening the press mold and operation of the push rod, grasping the casting and removal of it beyond the work zone of the machine after opening of the press mold and pushing of the casting from it, cooling of the casting, transfer of the casting to the finishing press and placing it in the oriented position in the die to remove the gate and sprue, removal of the casting from the die to packaging, cleaning and lubrication of the press mold before each pressing or in a specific cyclic mode, lubrication of the press chamber and of the press piston, checking the completeness of the removal of the casting, checking and adjustment of the main manufacturing parameters of the process, maintaining the given temperature conditions of the press mold, and heating the press mold at the beginning of operation are automated in pressure die casting complexes.

The engineering version of robotized complexes produced by Soviet industry can be different as a function of the type of machine to be used and also as a function of the nomenclature and serial output of the castings. The metal can be poured into the press mold both by pouring manipulators and by various types of automatic proportioning devices. The press molds are sprayed either by the robots or by a built-in nozzle system. Industrial robots in automated pressure die casting complexes can perform the most diverse functions from simple removal of the casting from the press mold to transport of the casting to the cooling operation and to subsequent delivery in a strictly oriented position to the ground mass of the finishing press, and then to the receiving hopper or to a conveyer. The robot not only performs manipulation motions with the casting according to a given program, but also controls all the related dependent equipment, clearly maintaining the cyclicity of all the operations to be performed and arranging the main production equipment in an operating rhythm.

Machines with cold press chamber are most frequently used in robotized pressure die casting complexes. Both universal robots and manipulators, designed to perform various operations with a wide range of parts, and special robots having limited capabilities of movement and which perform quite specific simple manipulation, are used as a function of the specific production.

A diagram of the robotized pressure die casting line of the Tiraspol Litmash Plant, which includes a pressure die casting machine 9 with locking force of 1,600-4,000 kN, a SAT-0.16 or SAT-0.25 bale-out pot furnace 6, vertical or horizontal finishing mold 10, an industrial robot to remove the casting from the press mold, to move it beyond the work zone of the machine and to place it in the stamp of the finishing press, a device 2 for checking the completeness of removal of the casting, and electric equipment 7 and 8 of the line and an automatic manipulator for pouring the metal, respectively.

Automated pressure die casting complexes of the Tiraspol Litmash Plant are used to manufacture castings weighing up to 6 kg on machines with a horizontal cold molding chamber. An additional operation of cooling the casting before finishing it is required in manufacture of casting weighing more than 6 kg, which is also performed by an industrial robot.

An automated complex of the Novosibirsk Siblitmash Plant is designed to manufacture castings weighing more than 10 kg on machines with horizontal cold molding chamber (Figure 3.2). The automated complex for pressure die casting includes a machine 1 with pressing force of 6,300-35,000 kN, electric equipment 2 and monitoring and measuring apparatus 3 of complex, a press mold thermostating device 4, vertical hydraulic finishing press 5, a unit 6 for spray (shower) cooling of the castings, an industrial robot or special manipulator 8, a unit 9 for cleaning and lubrication of the press mold, which includes devices for performing these operations and preparation of them, an electric bale-out pot furnace 11, and a proportioning manipulator or pneumatic proportioning device 12. The complex is controlled from a control console 10. A safety platform 7, which automatically interlocks the robot when the operator steps on it, is provided in the operating zone of the robot.

The worker in a robotized complex is completely free of exhausting manual operations and his role is reduced to observing the operation of individual mechanisms and of the complex as a whole. One operator can service the work of several automated complexes and pressure die casting lines.

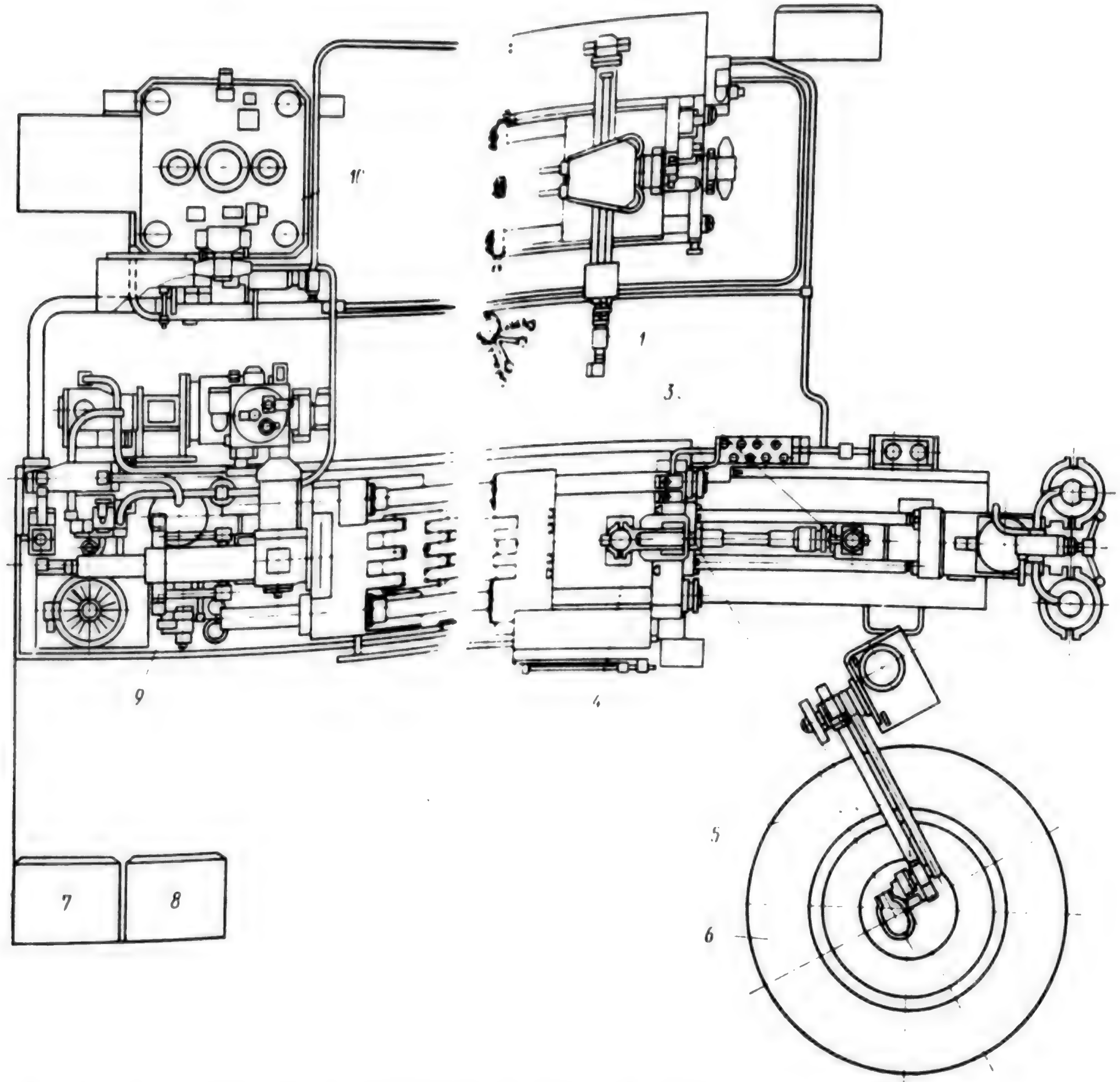

Figure 3.1. Diagram of Robotized Automated Pressure Die Casting

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A robotized pressure die casting line can be supplied with a complex programmed control system and a system for automatic maintenance of the parameters of the manufacturing process at a given level: the temperature and proportion of the metal to be poured, the temperature of the press mold, the locking force of the machine, the rate and pressure of molding, the rate of increase of pressure during molding, the length of aging the casting in the press mold, the force of removing the casting or of extracting the cores from it, and the tempo of operation, dependent on the length of the main and auxiliary operations. Information about the current values of the parameters of the manufacturing cycle of the operation of the complex to be checked can be sent to the shop process control system if need be.

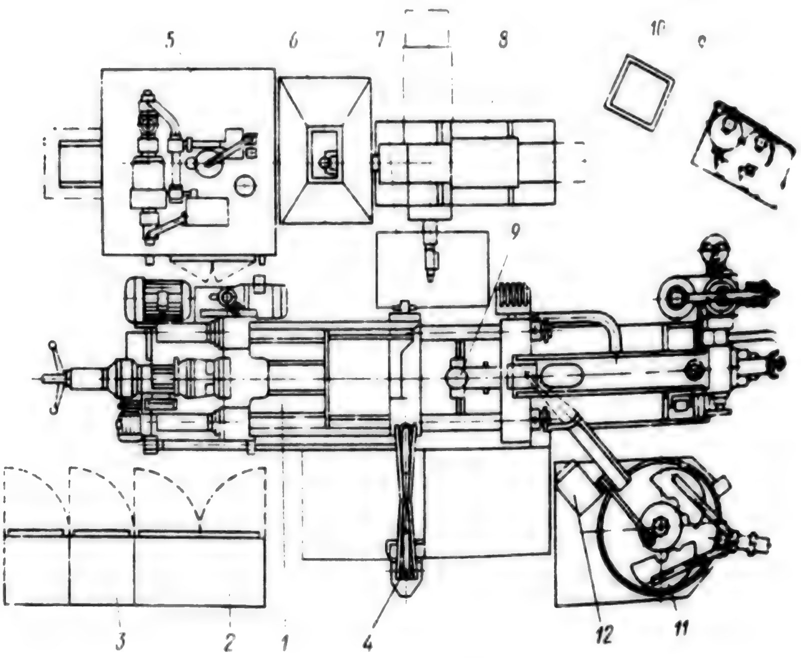

Figure 3.2. Automated Pressure Die Casting Complex

The parameters of the manufacturing process that determine the quality indicators of the castings are checked by using a measuring set of instruments through different types of sensors and pickups. The measuring set was developed by the Siblitmash Plant and is designed to supply a number of manufactured pressure die casting complexes.

Automation of manipulator operations for finishing castings and of inclusion of the finishing press into the pressure die casting complex require additional expenditures for equipment, area and maintenance; therefore, it can be effective only in large-serial and mass production of castings. If the productivity of the finishing press considerably exceeds that of the complex, there can be one press for several complexes. The industrial robot is used to remove the castings from the

press mold, to transport them from the operating zone of the machine and to drop them into a hopper or to transfer them to a conveyer (see Figure 3.2).

The main manipulator operations of a pressure die casting complex, model A711B09, are automated using a mechanical proportioning manipulator of model DM-4 (Figure 3.3), a manipulator 2 for lubrication of the press mold and an industrial robot 3, model LM10Ts.83.01 for removing the casting from the press mold. The castings are manufactured on a pressure die casting machine 4 with cold horizontal molding chamber, model 711B09 with the metal poured from a bale-out pot furnace 5, model SAT-0.16. The industrial robot set includes a control system 6 and control console 7. The lubricating composition is delivered to the manipulator 2 from a tank 8.

KOM-1.25E, KOM-2.5, KOM-5 and A-97 near-machine mechanization complexes, designed to supply machines with horizontal cold press chamber and locking force up to 10,000 kM, are manufactured by the Pinsk Forge-Press Equipment and Automatic Foundry Line Plant for automation of the manufacturing operations of the existing stock of pressure die casting machines. The set includes a device 3 for automatic lubrication of the mold chamber, manipulators for pouring the metal 4, for removing the castings 2, and for lubrication of the press molds 1 (Figure 3.4). The mechanization and automation equipment are selected from available special devices or they are developed specifically for the casting to be fabricated for machines having locking force greater than 10,000 kN.

One of the more crucial operations in pressure die casting complexes is that of pouring a strictly defined portion of metal at a given rate of filling the mold chamber and of moving the pouring container.

Pouring manipulators are used primarily when pouring small and medium portions of metal (up to 6 and 20 kg, respectively), since they ensure higher accuracy and stability of proportioning of the metal to be poured, compared to pneumatic proportioning devices, previously used for these purposes. Larger portions of metal (from 20 to 50 kg) are poured as before by automatic pneumatic proportioning devices, designed by NIISL [not further identified], SKBTL [not further identified], NIITAvtoprom [Scientific Research Institute of Technology of the Automotive Industry] and also by magnetodynamic proportioning devices designed by IPL AN USSR [not further identified].

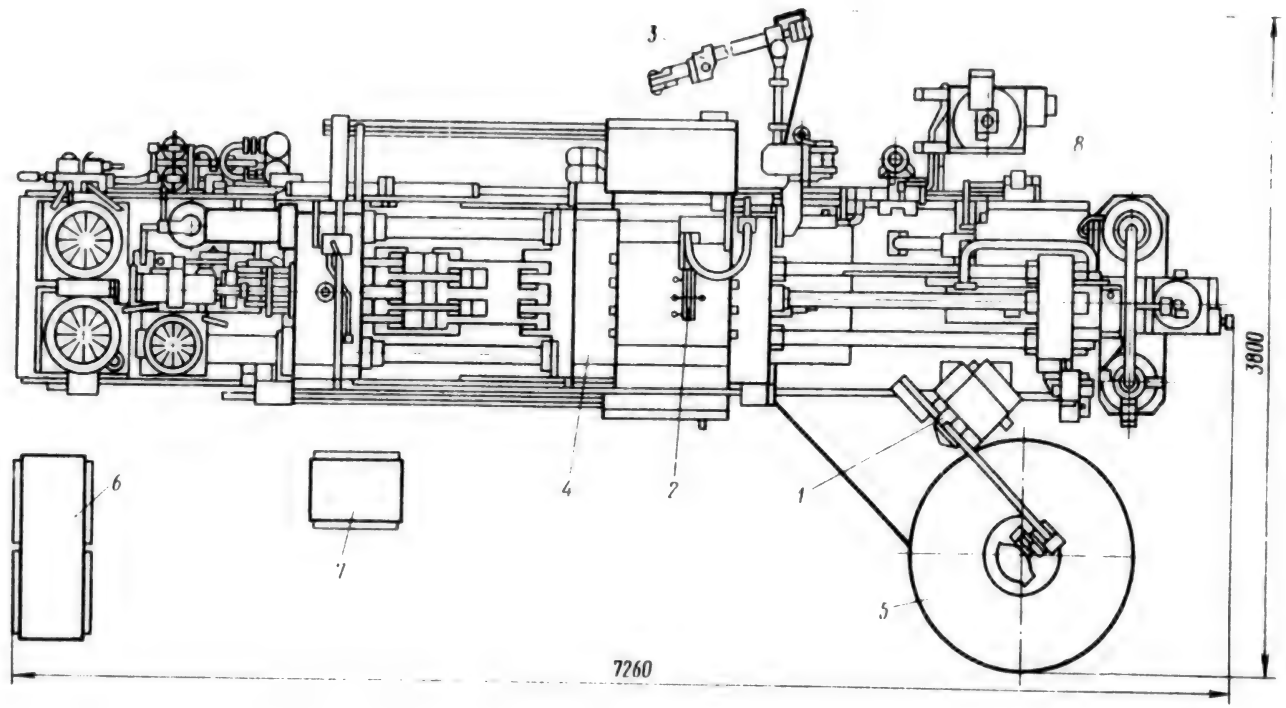

Figure 3.3. Robotized Pressure Die Casting Complex, Model A711B09: 1--DM-4 proportioning manipulator; 2-press mold lubricating manipulator; 3--LM10Ts.83.01 industrial robot for removal of castings from press mold; 4--model 711B09 pressure die casting machine; 5--model SATO.16 bale-out pot furnace; 6--industrial robot control system; 7--robot control console; 8--tank for lubricant lubricant

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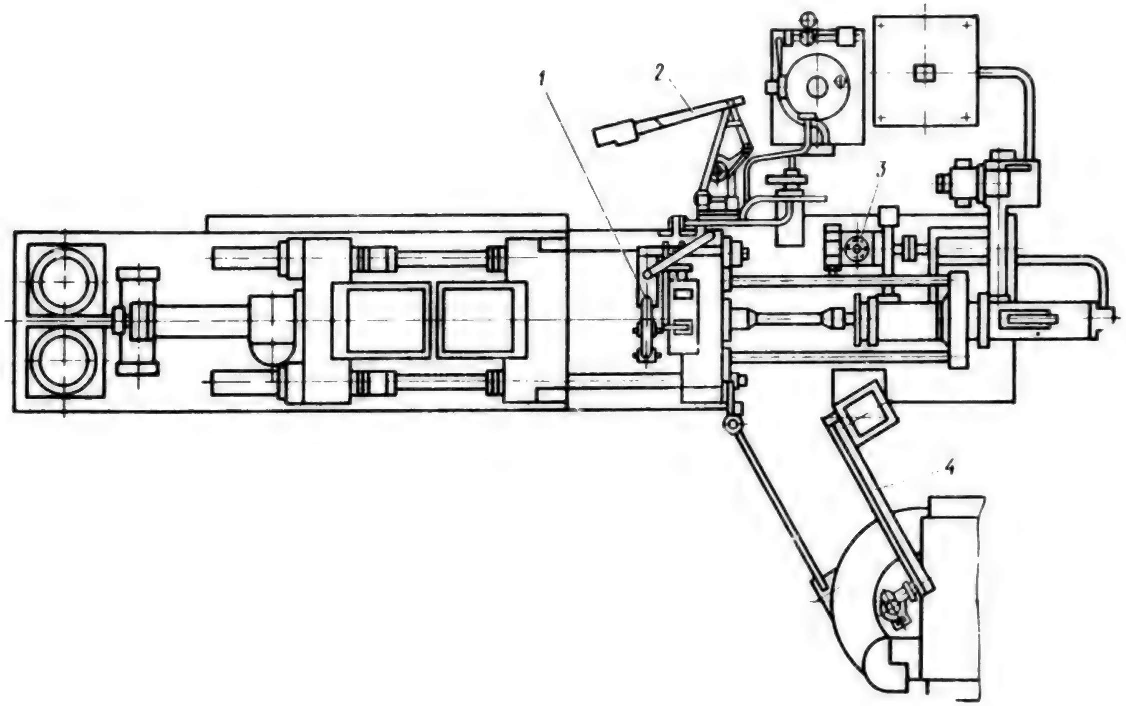

Figure 3.4. Diagram of Supplying Pressure Die Casting Machine With KOM Near-Machine Mechanization Complex

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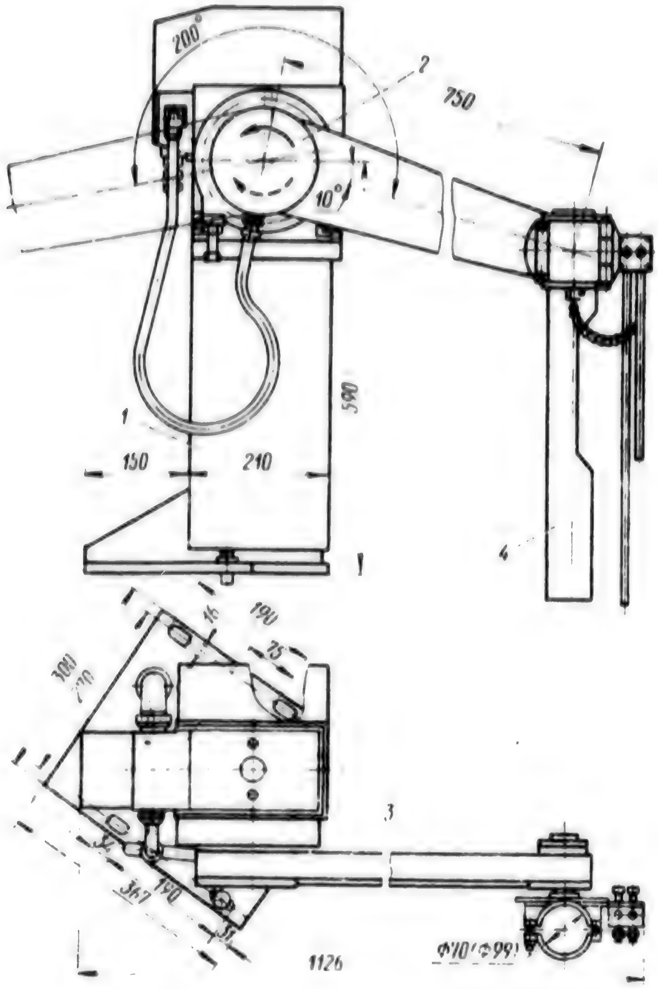

Figure 3.5. LM20Ts82.05 Pouring Manipulator
With Hydraulic Drive:
1--support; 2--lever moving mechanism;
3--lever mechanism; 4--pouring bucket

LM5Ts82.04 and LM20Ts82.05 pouring manipulators with hydraulic drive (Figure 3.5), which have operating reliability and which ensure smoothness of motions and holding the pouring bucket above the metal surface for draining the excess are most widely used. However, the operating characteristics of the manipulator and accordingly the accuracy of positioning change as the temperature in the hydraulic system varies, which is especially reflected in pouring small portions of metal. LM5Ts82.04 manipulators are not being replaced by DM-4 manipulators with electromechanical drive with pantograph mechanism for transporting the bucket to the pouring opening of the pressure die casting machine with locking force of 2,500 and 4,000 kN (Figure 3.6). The drive of the lever mechanism for transporting the bucket is electric and includes a DC electric motor and worm reduction gear. The bucket is

tipped when the metal is poured into the mold chamber by a chain drive through the worm reduction gear from an independent DC electric motor. The use of three types of pouring buckets, designed for rated weight of delivered aluminum alloy of 2, 3.6, and 6 kg, is provided in the manipulator.

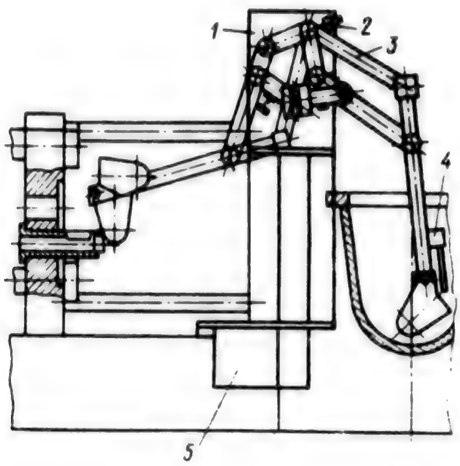

Figure 3.6. DM-4 Proportioning Manipulator:
1--electromechanical drive of manipulator;
2--sensor for switching on bucket tipping mechanism during pouring; 3--link of lever pantograph mechanism;
4--metal level sensor; 5--bracket for attaching manipulator to machine

The rated proportioning accuracy of pouring manipulators does not exceed 1.5-2 percent, while the time of transporting a portion of metal is 3-6 s.

The advantages of proportioning manipulators are manifested in the high proportioning accuracy, regardless of the fluctuation of the level of metal in the bail-out pot furnace, in their speed when providing a more economical bucket transport trajectory, which ensures safe stopping of the bucket and metal without splashing, and in the possibility of draining the metal into an auxiliary tank or back into the furnace.

LMS manipulators, mounted either on a fixed (for machines with horizontal molding chamber) or movable (for machines with vertical molding chamber) slab of machines with locking force of 1,600, 2,500 and 6,300 kN and which include from 5 to 10 nozzles for spraying the release agent, lubricate and clean the press molds in automated pressure die casting complexes.

A typical design (a) and a functional diagram (b) of a manipulator for lubricating the press mold are presented in Figure 3.7. The design of the manipulator includes a support 1, pneumatic moving mechanism 2,

panel 3, nozzle module 4, blowing frame 5, reduction gear 6, and also a mechanism for delivery of the lubricant and an electric cabinet with control console.

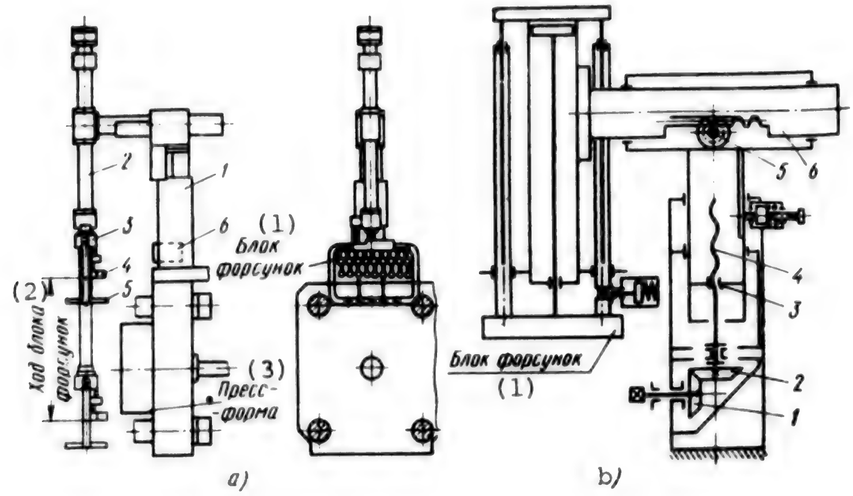

Figure 3.7. Typical Design and Functional Diagram of Manipulator for Lubrication of Press Molds

KEY:

1. Nozzle module
2. Course of module module
3. Press mold

The movable nozzle module is regulated in two coordinate axes moving bevel pinions of reduction gear 1 and 2 (Figure 3.7, b) and a helical gear 3 and 4, and also rack and pinion 5 and 6. The course of the nozzle module of LMS-63, LMS-80, and LMS-125 manipulators is equal to 630, 800 and 1,250 mm, respectively. The press mold is lubricated either during each operating cycle of the machine or according to a cycle counter every six cycles.

The press mold is lubricated and blown with compressed air by one of the following methods:

the press mold is blown out from above or below during the course of the movable nozzle module, while lubricating material is sprayed when the module stops in the lower position within a regulated time interval;

lubrication is performed during the downward course of the movable module, while blowout is performed during its upward course.

The manipulator can be located either in a fixed state or can perform rotary-forward motions up and down and can clean the press mold according to an assigned program during lubrication operations.

The mechanism for delivery of lubricant to the movable manipulator module is a separate unit, which includes a paint-heating tank for the lubricant, an air preparation system and a system for delivery of lubricating material in the continuous lubricant circulation mode (see Figure 3.2).

Removal manipulators of special designs, installed directly on the machine or made in the form of a stand-alone design, and also specialized industrial robots in different design version, operating in the same cycle as the machine, are used to remove the castings from the press mold.

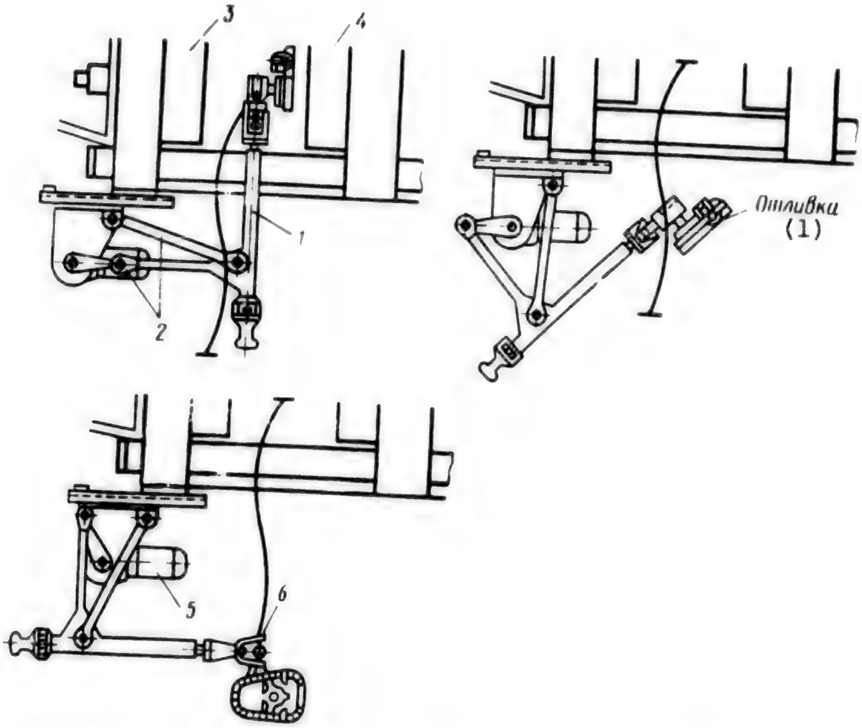

Figure 3.8. Diagram of Manipulator for Removing Castings From Press Mold

KEY:
1. Casting

A remover manipulator (Figure 3.8) is mounted on the fixed plate of a machine and is an articulated lever system 1, 2 with electromechanical drive 5. When the press mold is opened, a lever 1 enters between the halves 3 and 4 of the press mold and a clamp gripping device 6 clamps the casting behind the press and removes it beyond the working zone of the machine. The clamping device of the manipulator is rotated by 90° before releasing the casting and the casting is placed on a conveyer, in packaging or on a casting cleaning table.

Remover manipulators with hydraulic drive of type LM10Ts83.01, used in A711B09 automated complexes (see Figure 3.3), are used more widely for mechanization of simple manipulator operations. The working member of the manipulator also moves in the horizontal plane, with the exception of a gripping device.

In the operating mode, the manipulator mechanisms are switched on upon instructions from the machine and perform the following motions: insert of the lever into the joint of the press mold, delivery of the gripping device to the casting, clamping of the casting and release of the wrist, pushing the casting out with the hydraulic push rods of the machine, removal of the gripping device together with the casting from the movable part of the press mold, fixing the wrist, removal of the lever and casting from the operating zone of the machine, dropping of the casting, and return of the lever to the initial position.

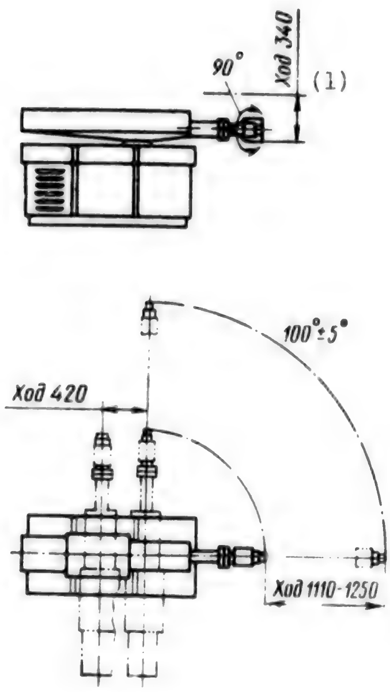

Figure 3.9. Diagram of Manipulator Movements of A9720 Industrial Robot

KEY:

1. Stroke

The mechanism for moving the manipulator is set in motion by a hydraulic drive, while the gripping device is fixed and the jaws are moved by a pneumatic drive. The smoothness of motion of the manipulator is

provided by a leak compensator, included in the set of equipment of the hydraulic station.

The use of universal industrial robots in pressure die casting complexes permits total automation of the casting manufacturing process.

The A9720 industrial robot (Figure 3.9) is designed to grasp and remove the casting from the operating zone of the pressure die casting machine with locking force from 6.3 to 10 MN and with cold horizontal molding chamber (see Figure 3.2). The sequence of possible movements of the working member with respect to the coordinate axes (entry of the gripping device into the joint of the press mold, grasping of the casting beyond the press residue, synchronous movement of the gripping device together with the casting simultaneously with extrusion of the casting along the axis of the machine, removal of the gripping device and casting beyond the operating zone of the machine, rotation of the gripping device by 90° about the horizontal axis, rotation of the robot turret for placing the casting in the cooling unit, placing the casting in the cooling zone, placing the casting in the joint of the die for finishing the gates and sprue, placing the casting in the die, removing the casting wastes from the finishing press, transfer of the casting wastes to packaging and release of the gripping device, and return of the working member to the initial state) is assigned by dialing the program on the control console as a function of the configuration of the press mold, of the method of the gripping device approaching the casting and of the desired manipulations with casting outside the operating zone of the machine. The absence of a finishing press or a unit for cooling the casting simplifies the program of motion of the working member of the robot. The capacity of the A9720 robot is 20 kg.

An RM-2 universal manipulator with capacity of 6.3 kg (Figure 3.11) is used in the DU711V08 automated pressure die casting complex (Figure 3.10) and it is designed to grasp the finished casting, to remove it beyond the operating zone of the machine, and to place it in the stamp of the P16A finishing press.

The carriage 1 of the manipulator (see Figure 3.11) is moved along the axis of the pressure die casting machine in the range of 320 mm. Mechanisms for lifting 4 and rotating 2 the manipulator and also a mechanism for response of a pincers-type gripping device 3 are located on the carriage. The pincers-type gripping device is moved back and forth by 800 mm. the accuracy of positioning the robot is ±0.5 mm. The jaws of the pincers are removable and their configuration should correspond to the shape of the gripping part of the casting or of the residue press.

The carriage is supplied with a regulating assembly, which permits one to compensate the free stroke of the rod of the hydraulic push rod of the machine until it comes into contact with the plate of the push rods of the press mold.

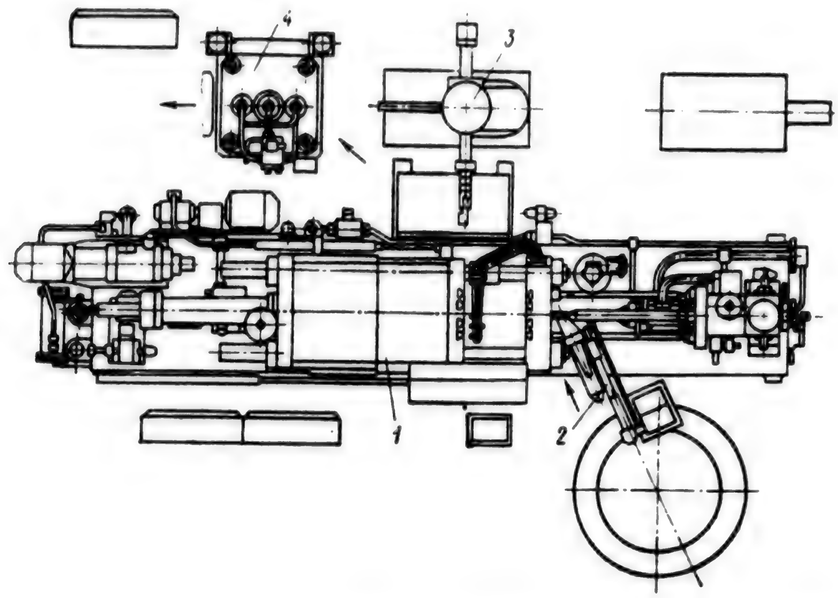

Figure 3.10. DU711V08 Automated Pressure Die Casting Complex: 1--711V08 pressure die casting machine; 2--pourer manipulator; 3--RMZA industrial robot; 4--vertical finishing press

A special robot designed to remove castings from a pressure die casting machine with horizontal cold molding chamber, for delivery of the castings to the cooling chamber and then to the horizontal finishing press, is shown in Figure 3.12.

The robot is attached to the fixed plate of the machine 1 and can be moved along the top column 2. The working member the robot 3 with gripping device 4 is introduced by horizontal motion inside the open press mold, grips the casting beyond the residue press and, moving along the axis of the machine, removes it from the press mold. The working member then removes the casting from the operating zone of the machine, rotates by 90° (position A) and moves vertically downward for cooling the casting in a cooling bath 5 (position B). The gripping device is raised upward, rotated upward by 90° toward the finishing press 6 and delivers the casting to the joint of the die (position C) for subsequent finishing of the castings. The manipulator operations of the robot, the sequence of performing them, and the value and direction of the stroke of the working member are regulated by a control system according to an assigned program.

Thus, the configuration layout of an industrial robot can be the most diverse and can include a manipulator device and moving devices, a programmed control system, manual control system, and system for completing an adjusting operating mode, a production equipment control system, and an information system.

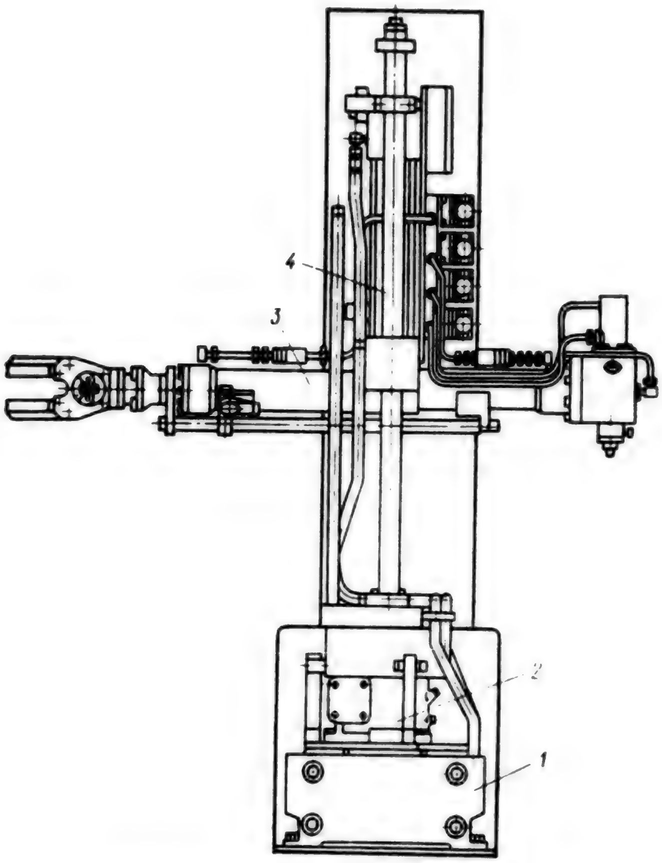

Figure 3.11. Remover Manipulator for Casting in Automated RM-2 Floor-Type Pressure Die Casting Complexes

The castings in robotized pressure die casting production complexes are finished on both vertical and horizontal presses. Each type has its advantages and disadvantages. Castings are easily placed in a vertical press, but it is difficult to remove them. It is easy to remove the castings and wastes in a horizontal press, but it is difficult to install a group of castings. The operating efficiency of an automated pressure die casting complex is sometimes enhanced when the finishing press is serviced by an additional manipulator.

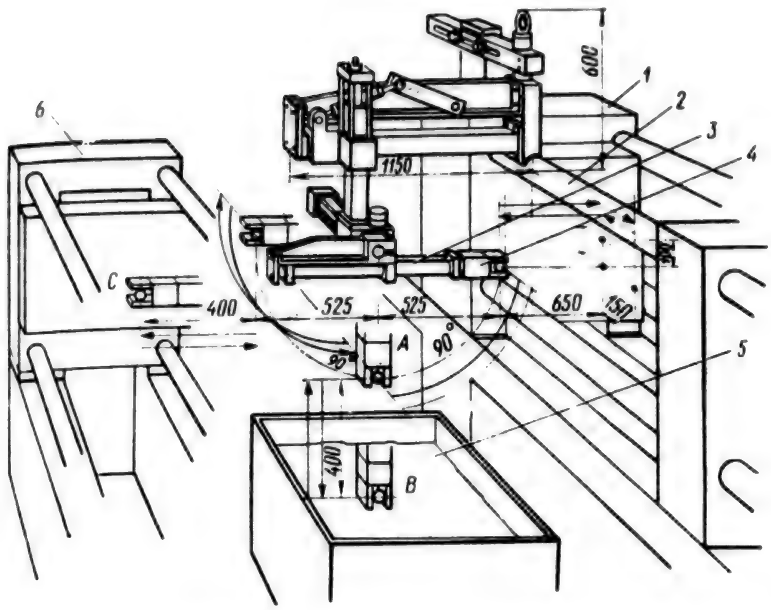

Figure 3.12. Diagram of Special Suspended Industrial Robot, Designed to Service Automated Pressure Die Casting Complexes

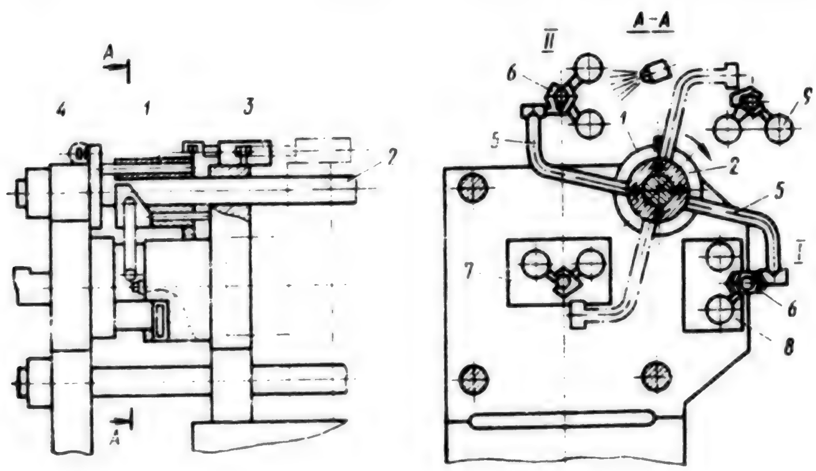

Figure 3.13. Diagram of Robotized Pressure Die Casting Complex With Combination of Operation of Finishing the Castings and of the Operating Cycle of the Machine

A very promising direction in development of robotized pressure die casting production complexes is combining the operations of shaping the casting and finishing both in time and place, using the hydraulic drive of the machine (Figure 3.13). A two-armed robot of original design, which is intended to remove a group of castings from the press mold and

to transfer it to the cooling position, for visual inspection and finishing, is used in the complex. The robot is mounted by means of a bushing 1 on one of the guide columns 2 of the pressure die casting machine with horizontonal cold molding chamber. The manipulator motions of the robot arms 5 together with gripping devices 6 are moved in the horizontal direction along the axis of the machine by hydraulic drive 3, and are moved in the vertical direction (rotation) by an electromechanical drive 4. After the press mold 7 is opened, the robot arm is inserted from position 1 into the joint of the press mold, the gripping device grasps the press residue, removes the casting in a synchronous joint motion with push rods and transfers it to position II for checking the completeness of removal and for air cooling, completed during one operating cycle of the machine. Upon subsequent opening of the press mold, the second arm of the robot enters the operating zone of the machine, is delivered by a horizontal motion to the press residue of the casting, after which the gripping device grasps it, at the same time as the first arm completes manipulation movements in the synchronous mode with the casting 9 cooled to given temperature. When the second arm removes the casting from the press mold and transfers it to the cooling operation, the first arm places the first casting into the recess of the finishing die 8. The halves of the die are mounted on the lugs of the plates of the pressure die casting machine, which permits one to combine the operations of manufacturing the castings and of finishing them in unit production equipment during one operating molding cycle. After finishing, the casting is pushed from the press die and is delivered to the hopper for collection of castings, while the production wastes are dumped by the gripping device to packaging after the finishing die opens.

The developed automated pressure die casting complex is distinguished by compactness, ease of service and checking of the technological parameters of casting, but it requires increased stiffness of the plates of the machine or of installation of additional support, and also an increase of the power of the casting machine drive or of the locking force of the press molds.

Success in the use of robots during automation of near-machine operations are related primarily to the characteristic features of the manufacturing process of casting--to a clear cyclicity of performing individual operation of the pressure die casting machine and strictly constant three-dimensional position of the casting at the moment it is removed from the mold.

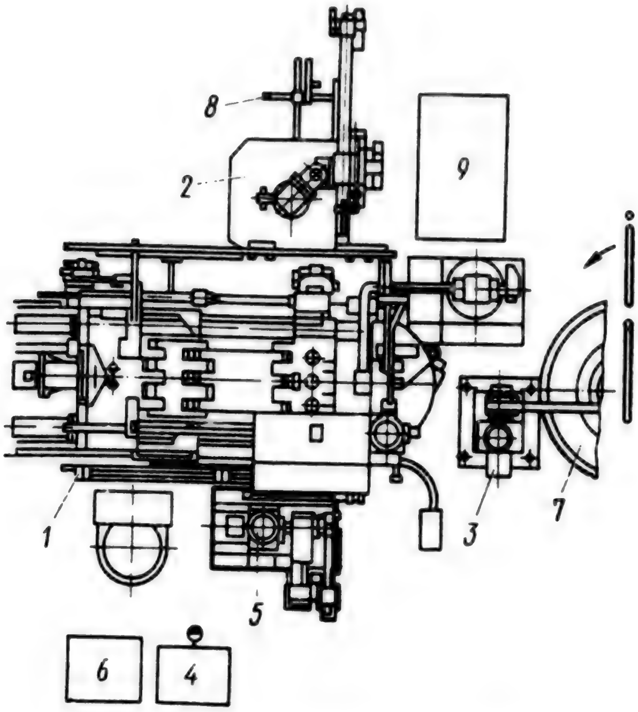

Figure 3.14. Diagram of Automated Pressure Die Casting Complex With Vertical Cold Molding Chamber: 1--pressure die casting machine; 2--industrial robot; 3--pourer-manipulator; 4--control console; 5--manipulator for lubrication of press mold; 6--programmable controller; 7--bale-out pot furnace; 8--device for checking completeness of removal of casting; 9--fettling press

Complete automation of the manufacturing operations can also be used on pressure die casting machines with vertical cold molding chamber. A diagram of a robotized pressure die casting complex with vertical cold molding chamber, produced in the CSSR, is presented in Figure 3.14. The castings are removed from the press mold of the machine by a robot, while pouring is performed by a pourer manipulator. The complex is controlled from a central control console.

3.2. Use of Robots in Gravity-Die Casting

The basic direction in development of the production of gravity-die castings is integrated automation and mechanization of individual phases of the manufacturing process of casting, beginning with preparation of the charge materials and preparation of the liquid melt and ending with removal, finishing, cleaning, checking and storage of the finished castings. The main manufacturing operations (opening the gravity-die mold, application of the refractory separating composition, installation and removal of the cores, closing and locking the gravity-die mold, pouring the metal, crystallization and shaping of the casting, removal

of the casting from the gravity-die mold, and thermostating of the gravity-die mold) are mechanized by machinery and accessories of the gravity-die mold or the casting complex, which the operator controls.

The units are controlled by a program using a computer when the technological process of manufacturing gravity-die castings is automated.

Automated gravity-die molds or mechanized gravity-die molds permit the greatest efficiency in serial and small-series manufacture of large castings, complex in configuration.

Mechanized gravity-die machines with vertical joint and crucible stool and also automated gravity-die complexes are supplied with remover manipulators and robots, designed to grasp the extruded castings, to transport them beyond the operating zone of the iron mold and to place them on the receiving table or transport device or on the die of the fettling press. Automated foundry gravity-die complexes also include manipulators for pouring the melt, units for thermostating the casting mold and for regulating the conditions of cooling the casting, and mechanisms for blowout and for spraying the working cavity of the mold.

An overall view of the 82A503 mechanized gravity-die machine, designed to manufacture castings in iron molds with vertical plane of the joint and crucible stool, is shown in Figure 3.15. The machine has mechanisms for main movable plates 6 and end plate 4, attached by a cantilever to the frame 5. The main plates are moved in the supports of fixed racks on two diagonally arranged guides by hydraulic cylinders 8. The end plate 4 is attached to a bracket on the rear side of the frame. The mechanisms of the main movable plates have an individual system for knock-out and fixing of the casting on the crucible stool and for returning the push rods to the initial position when the iron mold is opened completely. The crucible stool 7 also has a casting knock-out mechanism and a mechanism for removing the lower metal core if it is provided by the design of the casting.

An upper core mechanism 1, which is a kind of manipulator, is mounted on a rotary cross-piece on the right rack of the machine; it is designed to place, undermine, lift and move aside the upper plate and the metal core.

The casting is removed from the joint of the iron mold and is moved to the receiving hopper or to the belt of a chain conveyer by a manipulator 3, which consists of a pneumatic gripping device, lever system of the pantograph type, and hydraulic cylinders for lifting and lowering the gripping device and rotating it by 90°. The remover manipulator is attached to the left rack of the main plates.

An automatic system for cooling the machine and the iron mold ensures periodic on and off of cooling water delivery to the elements of the iron mold and of the machine.

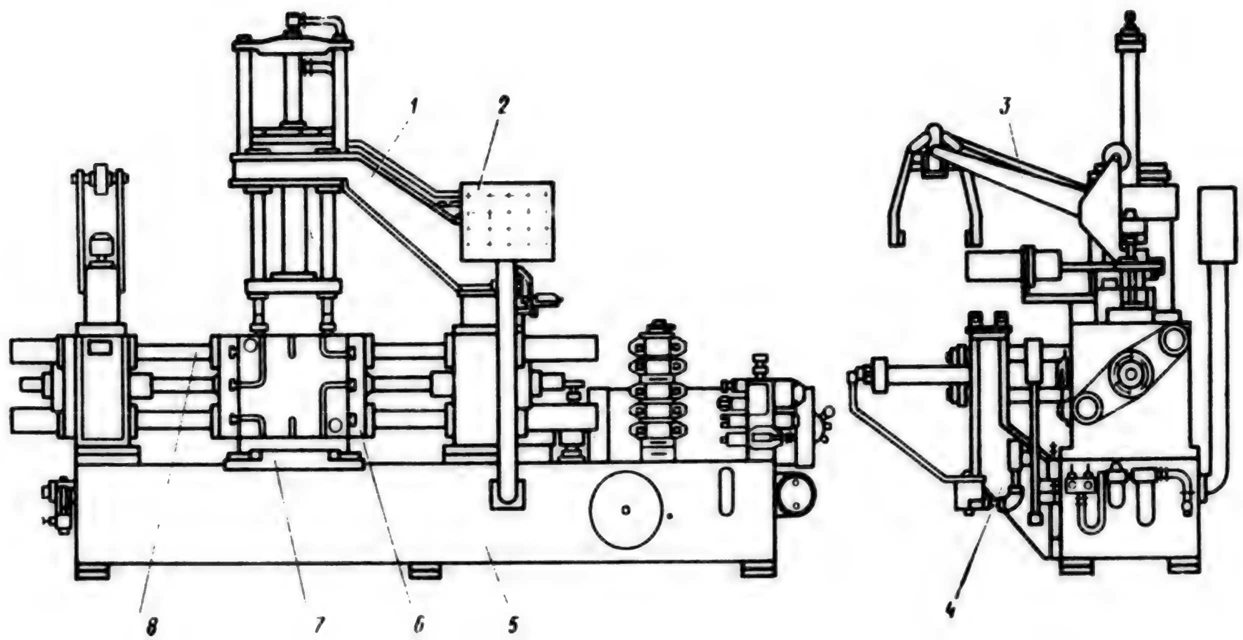

Figure 3.15. 82A503 Mechanized Iron Mold Machine

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The machine can operate in the semiautomatic mode, performing the following operations in sequence, provided by the cyclogram and by the manufacturing process: fettling the iron mold and applying a protective coating to its working surface, placing the metal cores, assembly of the iron mold (closing the movable parts), crystallization of the casting metal and cooling the iron mold, opening the iron mold and knocking out the casting, and removal and transfer of the casting to the receiving table or to the transporter. The metal is poured into the iron mold manually. A sand core is laid and the metal is automatically poured and proportioned by a manipulator if necessary when manufacturing aluminum alloy castings or by using a metal proportioning and consumption regulation system. The operation of the machine is controlled from a console 2, installed directly on the machine.

The 4942 automatic iron mold machine, designed to produce aluminum alloy castings in iron molds with a complex joint, with four moving parts, upper sloping metal core and crucible stool, has now been developed. The metal is poured by either a pneumatic proportioning device or by a pourer manipulator with bucket proportioning device. A manipulator is used to remove the castings. Introduction of the machine at the Kustanay Diesel Engine Plant increased labor productivity by 40 percent, conserved up to 50 g of metal in each casting, reduced rejected castings from 15 to 2-3 percent, and released two workers.

Automated casting complexes that permit total elimination of manual labor, improvement of working conditions, an increase of the quality of castings by precise and reliable main manipulator operations and stabilization of the parameters of the technological process of manufacturing castings within optimal limits have now been developed on the basis of one-position iron mold machines.

The A82A303 automated technological complex for gravity-die casting (Figure 3.16) of the Tiraspol Casting Machines Plant imeni S. M. Kirov includes two left and right one-position machines 1, joined by a common microprocessor control system 4, which ensures sequential manufacture of castings. The iron molds are filled alternately by a pourer manipulator 3 from a crucible-type SAT250 electric bale-out pot furnace 2. Each machine is supplied with an individual unit for thermostating the iron mold, which also ensures a given optimal cyclic operating mode of the machines and of the complex as a whole. The iron mold heat regulating and metal proportioning system during pouring ensures accuracy of the thermal casting modes, which determine the quality of castings and the structure and mechanical properties of the cast metal.

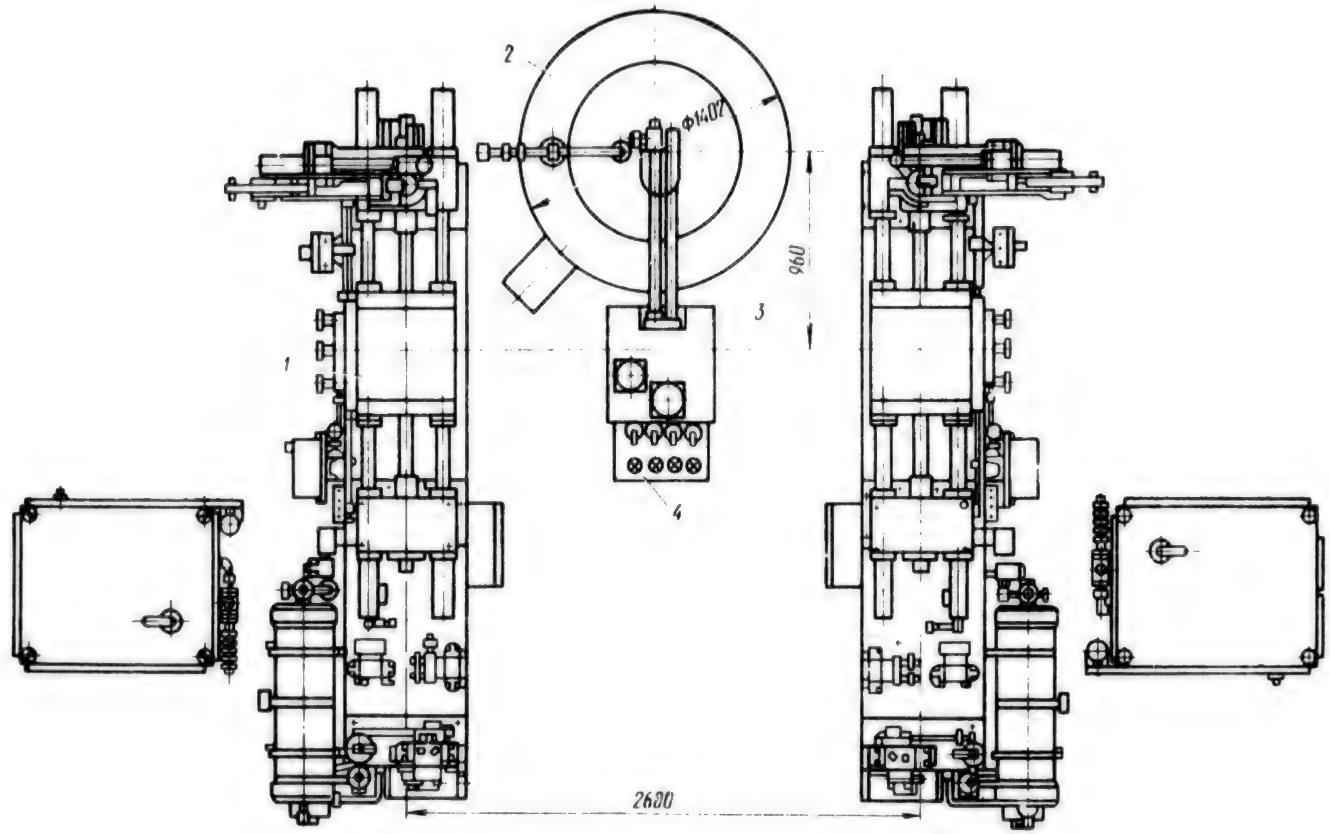

Figure 3.16. A82A303 Automated Technological Complex for Gravity-Die Casting

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Continuous-flow lines for gravity-die casting can be used in mass and large-series production of castings. These lines ordinarily consist of one-position semiautomatic machines or semiautomatic casting complexes, which include an automatic iron mold machine, a unit for pouring the molds, manipulators for removing the casting from the joint of the iron mold and for transferring it to the fettling press, units for preparation of the iron mold and for application of a separating composition to its working surface and robots for placing sand cores into the iron mold. The line may include automatic turret iron mold machines. An automated casting complex based on an eight-position turret machine is presented in Figure 3.17.

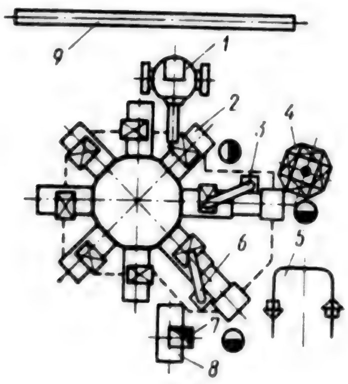

Figure 3.17. Diagram of Eight-Position Automated Iron Mold Complex

The turret is supplied with one-position iron molds 2, by which the melt is poured by a proportioning device 1. The complex is designed to manufacture castings of complex configuration with one-time sand cores, installed in the iron mold by a manipulator (robot) 3 from a distributor magazine 4. The castings are removed from the molds by a manipulator 6 and they are transferred to a press in an oriented position for fettling of the gates 8. The castings are delivered from the press to a hopper 7 and are then delivered to the micromodule stacks of a moving conveyer 5 and are transported for further machining.

NIISL jointly with SKBTL MPO Tochlitmash developed a series of automated and integrally mechanized lines for gravity-die casting when manufacturing castings of the same type under mass and large-series production conditions. They are manufactured by the Tiraspol Casting Machines Plant imeni S. M. Kirov.

An example of using the RDP-5 industrial robot for programmed casting of metal proportioning in automated iron mold complexes is presented in Figure 3.18. The robot 1 performs the following manipulator movements: selection of a specific proportion of molten metal from the bale-out pot furnace 4, transfer of the pouring ladle to the pouring position 2 of

the iron mold machine 3, rotation from the bale-out pot furnace to the iron mold, and pouring the metal through the sprue cup of the iron mold.

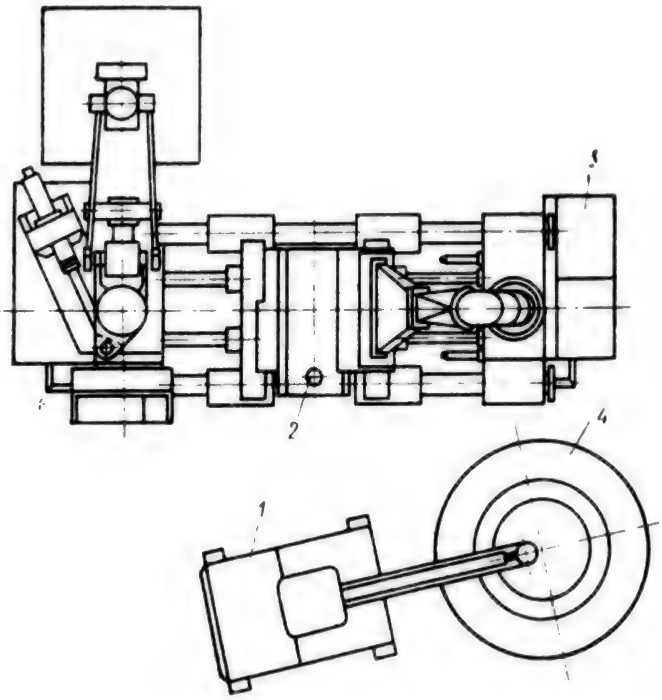

Figure 3.18. Automated Gravity-Die Casting Complex

A diagram of the A82M automatic line for casting into lined iron molds is presented in Figure 3.19. The following manufacturing operations are performed on the line: application of a heat-insulated lining, assembly of the iron molds, pouring the casting molds, opening the iron molds and removal of the castings, fettling and thermostating of the iron molds, and tipping the iron molds. The separate manufacturing sections are connected to each other by friction drive storage conveyers.

A heat-insulation coating is applied to the working surface of the iron half-mold with horizontal joint on a four-position sandblasting-turret unit 1. The iron half-mold is removed from the sandblasting unit by the PU401 manipulator and is transferred to a roller conveyer 2, where cores can be installed if needed. The iron half-mold is then transported to the assembly unit 3, from which the assembled iron molds are transferred to the roller conveyer 4 of the pouring section.

The assembly unit consists of an assembly manipulator, mechanism for turning the iron mold, and a drive roller conveyer. The lower iron half-mold is raised by these mechanisms until it contacts the upper iron half-mold. The assembled mold is lowered by a hoist to a conveyer and is rotated by 180°.

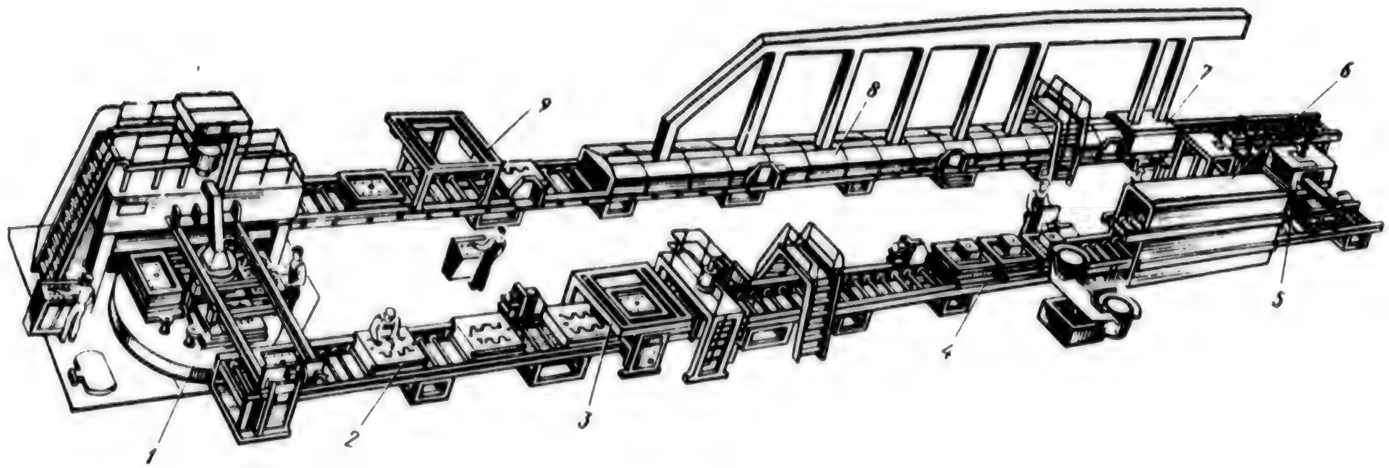

Figure 3.19. A82M Automated Line for Casting Into Lined Iron Mold

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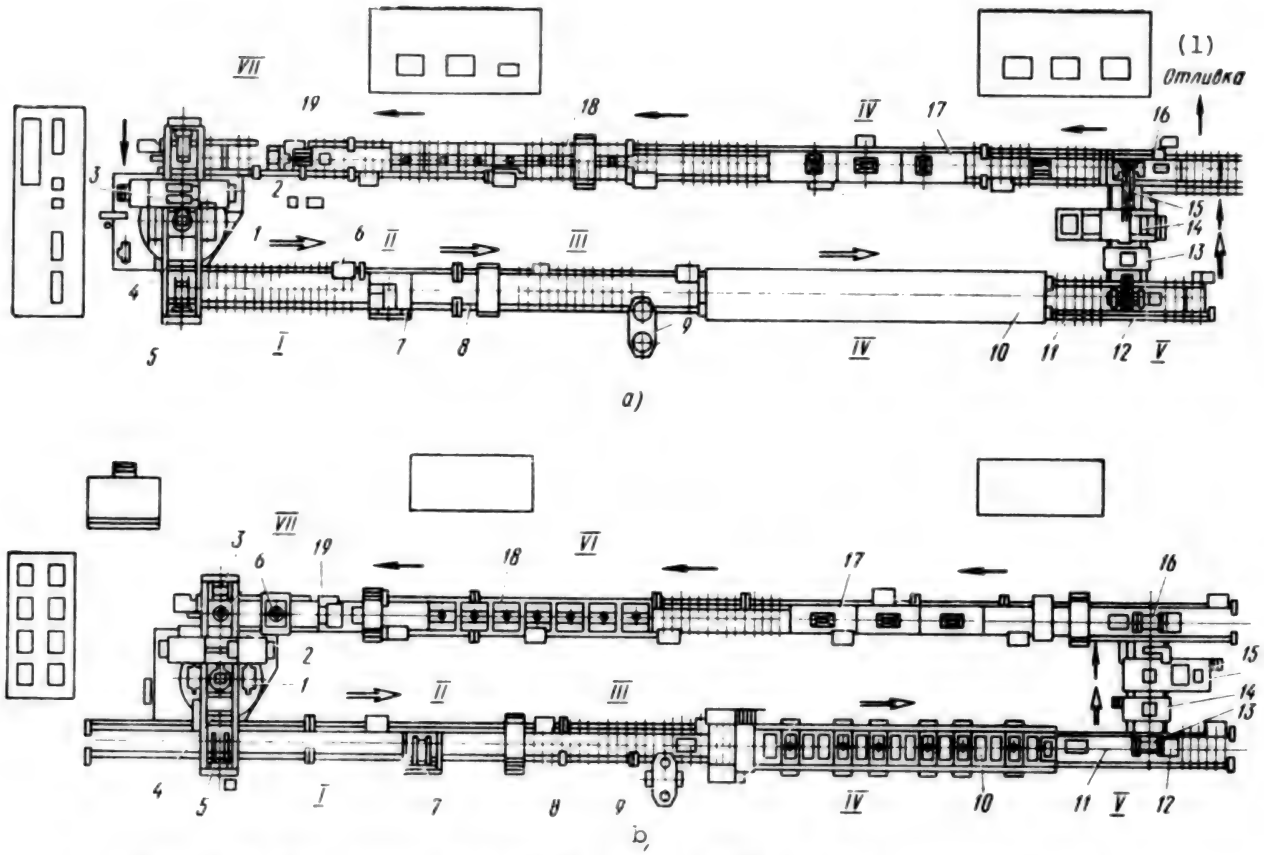

Figure 3.20. Layout of A82M (a) and A96 (b) Automated Lined Gravity-Die Casting Lines
1--turret-sandblasting unit; 2--iron mold loading manipulator; 3--iron mold loading hoist; 4--iron mold removal manipulator; 5--iron mold removal hoist; 6--blowout opening fettling mechanism; 7--iron mold assembly manipulator; 8, 11--roller conveyers; 9--pouring machine; 10--thermostat; 12--push rod-splitter; 13--lifting table; 14--iron mold separation manipulator; 15--manipulator for broaching broaching lower half of iron mold; 16--receiving table; 17--iron mold fettling device; 18--cooling chamber; 19--tipper

KEY:

1. Casting

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Clamp mechanisms attach the halves of the iron mold to each other in the pouring section. The molds are stopped by a special stopping device in the metal pouring position. The molds are filled from the L746 two-position pouring machine.

Three iron molds poured simultaneously are delivered to a thermostat 6, where they are cooled or, if the line stops, molds prepared for pouring are stored. The thermostat is two-level for this reason.

The filled and cooled molds are transferred to the iron mold separation section 5, where the iron mold is separated by using a hoisting table, knock-out rods, separation manipulator and broaching the lower half-mold, a mechanism for shearing the lining, a receiving table and friction drive conveyer. The casting is knocked out and the blowout openings and working surface of the iron mold are cleaned of the heat-insulating coating.

The iron mold is cleaned of residues of lining by compressed air in the iron mold fettling device 7.

The iron half-molds are cooled to the given temperature in section 8, from which they are transported along a roller conveyer to a tipper 9 and then to the PU409 iron mold loading manipulator, which moves them to the sandblasting-carosel unit 1.

The layouts of A82M and A96 automated lines for producing castings in lined iron molds are presented in Figure 3.20. The lines are a closed rectangle. The lines include separate sections having independent control, in which different manufacturing operations are performed (I--application of the heat-insulating lining to the iron mold; II--assembly of the iron molds; III--pouring metal into the iron molds; IV--crystallization of the casting and cooling of the iron mold; V--separation and fettling of the iron mold; VI--cooling the iron half-molds; and VII--tipping and preparation of the iron half-molds). The machines, units and mechanisms of the lines are connected to each other by drive roller conveyers with friction rollers, which ensure operation of the sections in a given mode. Moreover, their operation is controlled by the iron molds, which occupy operating positions in the operating zone of the machine or mechanism.

3.3. Use of Robots in Manufacture of Castings in One-Time Sand Molds

The main problem in mechanization and automation of foundry production by using industrial robots and manipulators includes rational tie-in of the hoist-transport and technological operations that participate in the production flow to each other.

From the viewpoint of automation and integrated mechanization of foundry production, the technological process of casting manufacture should be viewed as a single whole, connected by specific principles, determination of which permits strict optimization and clear

organization of casting production, rather than as an arrangement in a number of individual technological operations.

Organization of continuous production envisions implementation of a number of measures of an organizational and technical nature, the main ones of which are:

working out the technological process of casting manufacture with separation of it into the simplest operations;

ensuring synchronism in performance of technological operations, i.e., achieving equality or brevity of time of performing an operation, of individual elements, and procedures when working on a continuous line;

development of conditions of the sequence, exactness and continuity in the manufacturing process (for example, production of castings on a continuous automated lined gravity-die casting line, see Figure 3.20);

introduction of means of mechanization, integrated mechanization and automation in completion of the main technological operations and operations of auxiliary and organizational maintenance;

achieving a high degree of loading of interconnected equipment, of the work places on the continuous line in their productivity and so on.

An assembly drawing and operating cyclogram for each specific point of installing an industrial robot must be worked out with regard to its type, the process flow diagram and characteristic features of production, where the arrangement of the production equipment and conveyers, the position and attachment of the robot, delivery of supply lines, composition and arrangement of external sensors that synchronize the operationn of the automated complex should be indicated, and those changes in the production equipment which permit the industrial robot to be joined with them must be taken into account when designing automated manufacturing systems using industrial robots.

Based on the above prerequisites, automation of the technological processes of foundry production using robots is possible only under conditions of a principal organizational-ordered nature of operations, inherent to continuous conveyer production and to rotary (turret) lines.

When manufacturing casting molds on automatic turret shaping machines with combination sealing process (Figure 3.21, a), manipulators are used to tip the half-mold, to broach the model and to install the replaceable plate and standard plate on an automatic machine. An automatic turret molding machine includes a KL22821 automatic molding line. The automatic machine has four positions. Blowout and spraying of the model occur in position I, the mixture is poured and it is first packed in position II, packing is accomplished with subsequent molding in position III, while the packed half-mold is tipped in position IV.

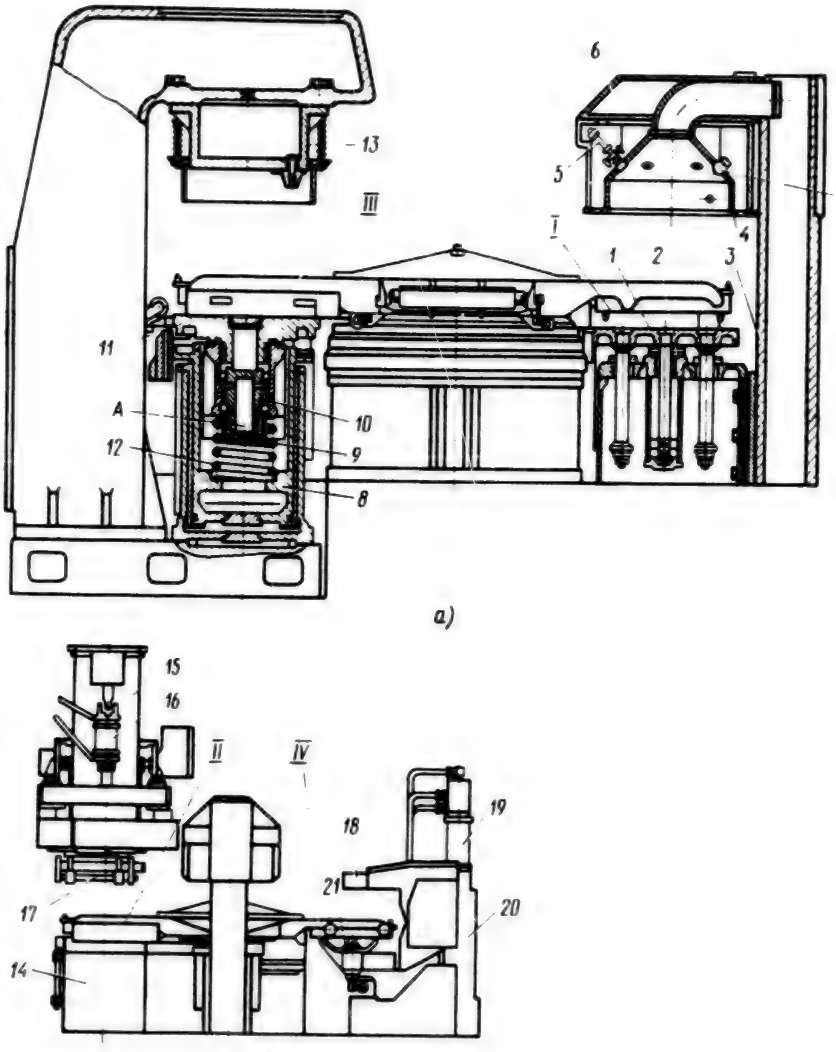

Figure 3.21. Four-Position Turret Automatic Molding Machine With Combination Packing Process:
1--hoisting table; 2--pneumatic cylinder; 3--column; 4--model fettling chamber; 5--kerosene spraying nozzles; 6--tank containing kerosene; 7--fettling nozzle; 8--press piston; 9--shaking cylinder; 10--shaking piston; 11--table of molding machine; 12--shock absorber spring; 13--press plate; 14--two-stroke table; 15--hopper with shaping mixture; 16--jaw-type pneumatic cylinder; 17--gripping device; 18--spraying of top molding box; 19--hydraulic cylinder for rotation of actuating member of manipulator; 20--housing of manipulator;. 21--clamp of top molding box

The manipulator consists of a housing 20, clamps 18 of the top molding box, clamps 21 of the removable bottom plate, and a rotating hydraulic cylinder 19. When the molding box is delivered to position IV (Figure 3.21, b), it is clamped and the entire set is rotated by 180°. The half-mold receiving table is in the upper position. The molding box is then emptied and the half-mold receiving table is lowered, broaching the model. The manipulator, returning to the initial position, installs a removable plate from the model plate to an automatic machine.

The automatic machine is designed to manufacture small core molds of complex configuration in molding boxes measuring 500 × 400 × 150 mm and the upper and lower half-molds are molded sequentially. The half-molds are delivered to an adjacent conveyer for placing the cores and assembly of the molds. In the given case, the manipulator becomes part of the automatic turret-type molding machine and performs very specific functions of limited action, which do not permit its use for automation of manipulator operations to transfer finished half-molds to the casting conveyer.

Semiautomatic molding machines, connected to the casting conveyer by manipulators, are installed under conditions of small foundry shops with limited areas, where integrated automatic lines can not be located. An example of these lines with molding machines and manipulators, located inside (Figure 3.22, a) and outside (Figure 3.22, b) the casting conveyer, is presented in Figure 3.22. The line includes a casting conveyer 1, loader 2, mold cooling section 3, casting knock-out section 4, molding section 5 supplied with molding machines for top and bottom half-molds, manipulators with rotation of the molding boxes 6 and without rotation of them or of half-molds 7 and roller conveyers 8.

After the castings are knocked out, the paired empty molding boxes are delivered by the casting conveyer to a manipulator 7, which removes the molding box of the top half-mold from the conveyer and sets it on the molding machine for the mold-formation operation. The molding box of the bottom half-mold is transported to a manipulator 6, where it is removed, rotated by 180° and is also formed. The bottom half-mold is rotated by another manipulator by 180° and is set on the casting conveyer, where the casting molds are assembled by the manipulator, working in pair with the molding machine for the top half-molds. The manipulator removes the molding box of the top half-mold from the table of the molding machine and covers its bottom half-mold. If there are cores in the mold, they are set in the bottom half-mold when it moves from the molding machine to the bottom half-molds to the assembly point or on the casting conveyer (Figure 3.22, a) or on the assembly conveyer (Figure 3.22, b). The assembled casting mold is then loaded by loader 2 and is transported to the pouring operation and then for cooling and to the casting knock-out section 4.

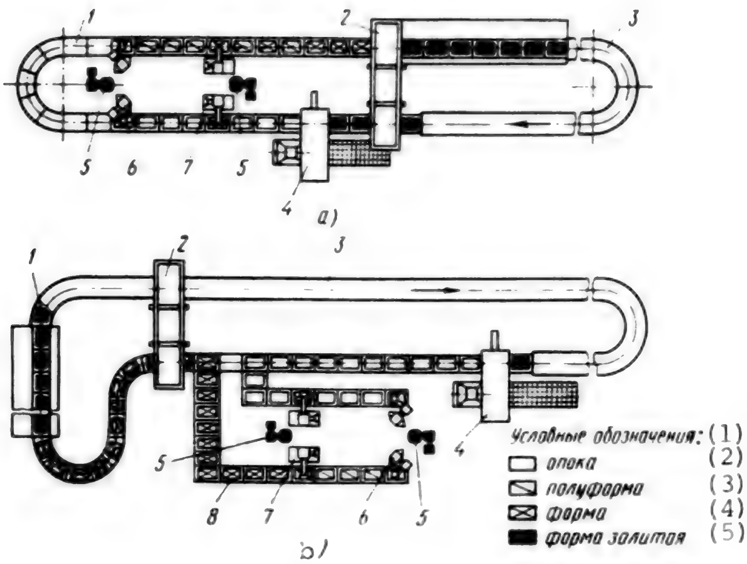

Figure 3.22. Automated Conveyor Foundry Lines for Manufacture of Castings in One-Time Sand Molds

KEY:

1. Notations
2. Molding box
3. Half-mold
4. Mold
5. Filled mold

The automated casting lines are controlled by an electric system with relay-contact and contactless elements. The information carriers are the casting molds (molding boxes), which ensure response of the automatic control elements, of the fixing and clamping devices, acting on the end switches, issue instructions for operation of the manipulator, molding machines, loader, and pouring devices while moving from position to position. Electronic control systems of automated molding-pouring-knock-out casting lines with logic elements and software using a computer have now been introduced.

A robotized machine molding complex, consisting of vibration molding machines 1 and 3 for manufacture of bottom 6 and top 7 half-molds, an assembly branch of the casting conveyer 4 and an industrial robot 2, which serves for variable delivery of empty molding boxes 5 to the machines and for transfer of finished half-molds to the casting conveyer, is presented in Figure 3.23. The gripping device 9 of the industrial robot 2 grasps the molding box and half-molds for the journals. The molding machine 1 is supplied with a device for tipping the half-molds 10, which also serves to broach the model and to deliver the half-molds to the receiving rollers 11.

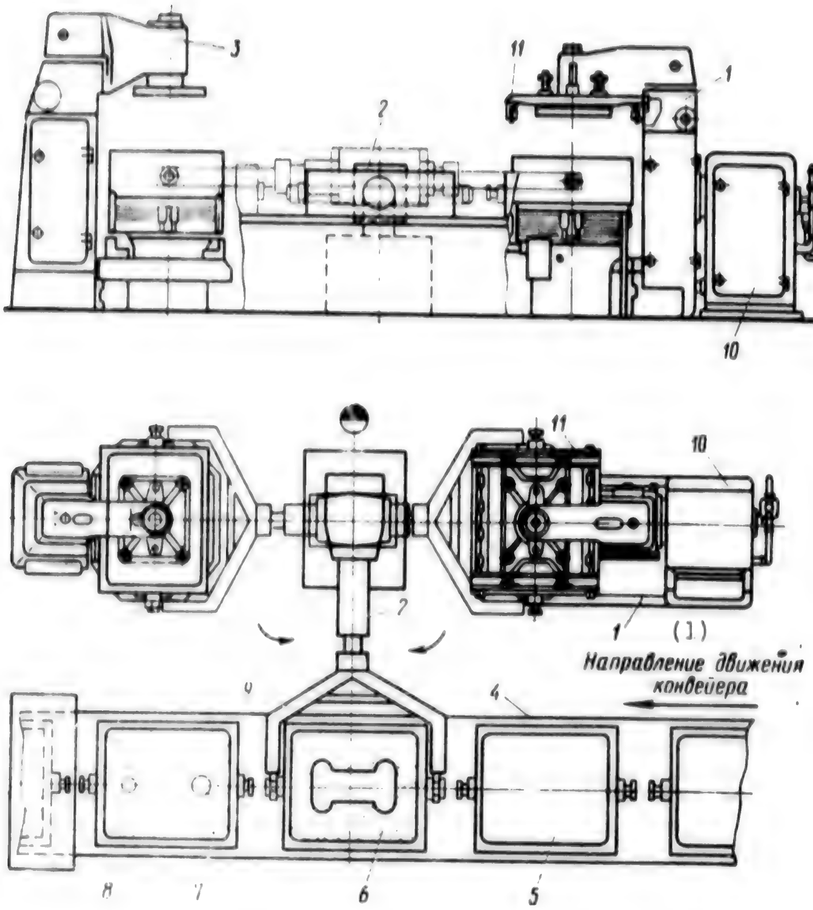

Figure 3.23. Robotized Machine Molding Complex

KEY:
1. Direction of motion of conveyer

The complex is supplied with a special monitor for checking the integrity of the imprint of the model in the half-mold and for automatic marking of rejected half-molds 8. Contactless quality control and checking of the completeness of the imprint of the half-molds is based on measurement of the intensity of the fluorescing glow of special composition, applied to the model before molding, by a system of photoelements of an analyzer during irradiation of the half-mold by fluorescent lamps. Signals are delivered from the photoelements through a microprocessor to a comparison module, where the coated qualitative image of the imprint of the model in the half-mold is compared to the actual model. As a result of comparing the images, the imprint of the model in the half-mold is set into agreement to qualitative criteria; otherwise the half-mold is marked as rejected.

The operating cycle of the industrial robot is compiled such that it performs the operation for maintenance of another machine when the half-molds on one machine are sealed and fabricated.

One of the most labor-intensive jobs on the casting conveyer is the operation of placing the cores and assembly of the casting molds; it can also be performed by using industrial robots (Figure 3.24). A robotized casting mold assembly complex on a conveyer 3 includes industrial robots: core placer 1 and mold assembler 2. The cores are delivered for the placement operation by an overhead gantry type conveyer, the motion of which is synchronized with that of the casting conveyer and with the operating cycle of the industrial robots. An industrial assembler robot 2 grasps the pins of the top half-mold 4, raises it above the casting conveyer 3, rotates it by 180° with the top downward, installs it on the bottom half-mold 5 and assembles the molds 6. The manipulation motions and operation of the robots are performed without stopping of the casting conveyer.

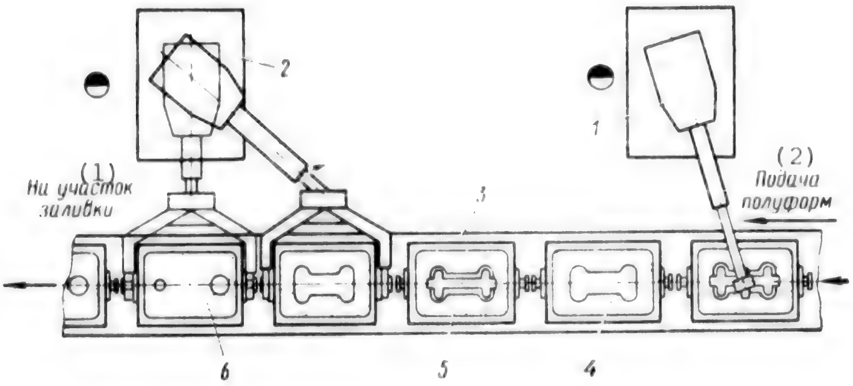

Figure 3.24. Robotized Core Placing and Mold Assembly Complex

KEY:

1. To pouring section
2. Delivery of half-molds

TsNIITEItraktoselkhozmash [Central Scientific Research Institute of Information and Technical-Economic Studies on Tractor and Agricultural Machine Building] has developed and introduced an automatic robotized line for producing castings of increased accuracy from ferrous and nonferrous metals in vacuum film molds. The line consists of 60 manipulator robots that perform all the technological operations of producing the molds automatically in a given sequence by the vacuum film molding method, and includes semiautomatic systems for placement of the model sets, pouring metal, and knock-out and cooling the castings. The line permits a significant increase of the flexibility of foundry production by manufacturing a broad range of castings of essentially any number of copies.

Industrial robots are beginning to be used in technological complexes for manufacture of cores (Figure 3.25) from hot-hardening sand-resin core mixtures. The robotized complex for manufacture of cores in hot boxes includes sandblasting core machines 1, belt conveyers 2 for receiving the cores 6, which fall from the core box when it is opened, a robot core layer 3, an overhead transport conveyer 4, and electric power and control cabinets 5. The gripping device of an industrial robot is supplied with orienting vacuum device, which is used to grasp, fix, and transfer the core 6 to a micromodule stack 7 of an overhead conveyer 4. The movements of the industrial robot, of the delivery belt conveyers and overhead conveyer should be strictly synchronized.

The considered robotized manufacturing complexes are a self-contained operating combination of production hardware (main production and auxiliary equipment and industrial robots), which ensure both a completely automatic operating cycle inside the complex and connection of it to input and output flows of the remaining plant.

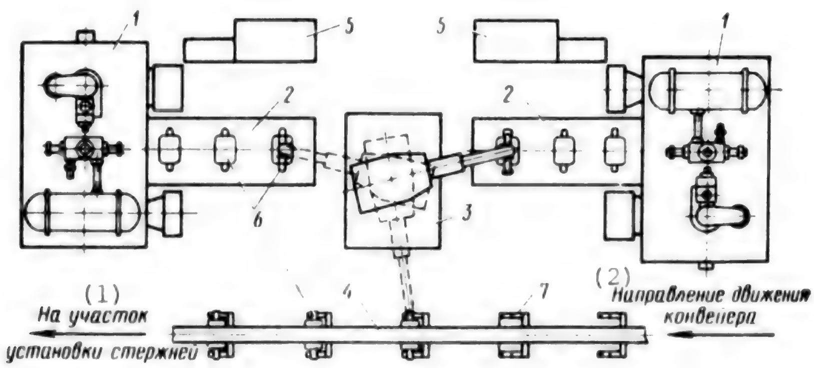

Figure 3.25. Robotized Core Manufacturing Complex

KEY:

1. To core placing section
2. Direction of motion of conveyer

The practice of leading enterprises showed that a positive effect can be achieved upon introduction of robots, especially in the composition of automated and continuous sections and lines, only by restructuring of production and by a fundamental change of technology (for example, one should sometimes reject traditional technological and engineering solutions and approaches, specifically, linear layouts of arrangement of equipment).

The use of automated manufacturing complexes based on industrial robots in foundries ensure automatic operation of various types of equipment and stability of the quality of castings without human participation.

3.4. Robotized Casting Investment Pattern Complexes

The main and auxiliary operations performed by industrial robots and manipulators when producing investment pattern castings should include installation and preparation of press molds (fettling and lubrication of the work surface, delivery of them for manufacture of the models (modules), assembly and disassembly of the equipment, delivery of the modules for transport, assembly of the model modules, shaping of ceramic shells, setting of shell molds on suspensions and removal from them, transport of ceramic shell modules for tempering and pouring, and delivery of filled modules for installation for separation of the ceramics and to the press for separation of castings from the rack. Robotization of investment pattern casting processes is a timely direction, since the volume of the output of castings produced by this method is growing continuously.

Manufacture of ceramic shells is the most labor-intensive; therefore, special attention is devoted to it in introduction of robot engineering for automation of the technological process of manufacturing castings by investment pattern casting methods. The technological operation of shaping ceramic shell molds includes the following main steps: transfer of the investment block to a bath containing a suspension, submergence of the investment block into the suspension to the upper level of the sprue cup at an angle of 30° with simultaneous rotation by 360° about the axis two-three times, raising the block above the bath with simultaneous rotation by 360° about the axis for draining the excess suspension, transport of the investment block to the sand fill, submergence of the investment block into the sand fill to the upper level of the sprue cup at an angle of 30° with rotation by 360° twice about the axis of the block (the weight of the block increases by 20-30 percent with application of each new layer of shell), raising the investment block above the sand fill with simultaneous rotation by 360° about the axis for draining sand from the dead zones, transport of the block and setting it on the conveyer suspension for subsequent drying of the shell layer.

A robotized system with industrial robots of the Unimate 400 model is used to automate the enumerated transitions of manufacture of ceramic shell molds when casting turbine blades and parts of aircraft and gas turbine engines. The robot performs the operation of application of a refractory suspension to the investment blocks and of a cushioning layer in the fluidized bed. The investment blocks are delivered to the work zone of the robot using an overhead conveyer on slabs under the investment block. The robot sequentially takes each investment block, dips it into the corresponding suspension, applies the cushioning layer and returns it to the investment block slab (the conveyer is fixed for the time the robot is operating). The investment blocks are then transported for drying. The cycle is then repeated using other suspensions and cushioning layers. The programs stored in the memory of the industrial robot are selected automatically according to signals of

a counter and an electronic reader, mounted on the robot's control console.

A total of 30-50 seconds are required for manual molding of the shell layer. The robot does the same job within 60-150 seconds, but use of it is more economically effective due to the continuous operation and stability of product quality.

The layout of an automated complex for manufacture of ceramic shells using a universal industrial robot is shown in Figure 3.26. Robotization of the process stabilizes and optimizes the technological transitions, reduces rejection of molds, and reduces the consumption of molding materials.

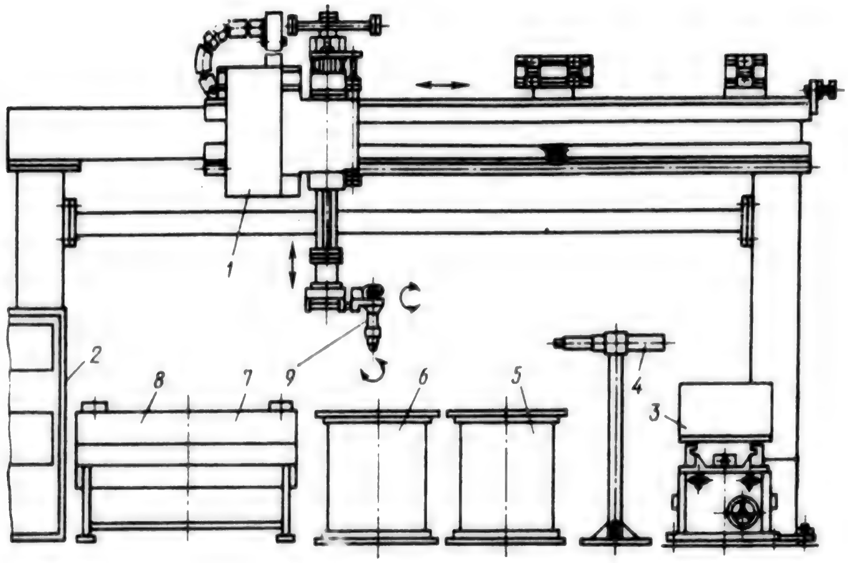

Figure 3.26. Layout of Automated Complex for Manufacture of Ceramic Shells:
1--gantry-type industrial robot; 2--control console; 3--storage device with investment blocks; 4--fettling device; 5, 6--sand cushioning layers; 7, 8--baths for suspension; 9--working tools of robot

The principal difference from the classical linear layout is the configuration of the production section using the UM-1P robot, when the necessary combination of industrial equipment is arranged about the industrial robot (Figure 3.27). A mobile platform 8 with suspended investment blocks rolls along guides to the work position and is automatically fixed by a hoisting-rotary device. The robot 4 grasps the investment block from a platform, transports it to a bath 5 and dips it into a suspension to the upper level of the sprue cup throat. The mechanism for rotation of the gripping device holding the investment block and a time relay for stopping the robot for a specific time

interval are then switched on according to auxiliary instructions of the program, during which the robot locates the block in the suspension, raises the rotated block above the bath and holds it for the excess suspension to drain off. The robot then transports the rotated block to one of the sand cushioning layers 6, lowers it into the pseudo-fluidized bed of sand and raises it above the sand cushioning layer with programmed stops of the robot arm in the sand cushioning layer and above it. The robot then carries the block to the fettling device 7 for cleaning the sprue cup throat of excess suspension and sand (when the excess suspension fettling device is cut with a blade, the robot rotates the investment block) and again places the block on the storage platform 8. The storage device has two platforms and is designed for installation of 40 investment blocks. The hoist-rotary device then rotates the storage platform by one step of suspension of the blocks and transmits a signal of readiness for a new cycle.

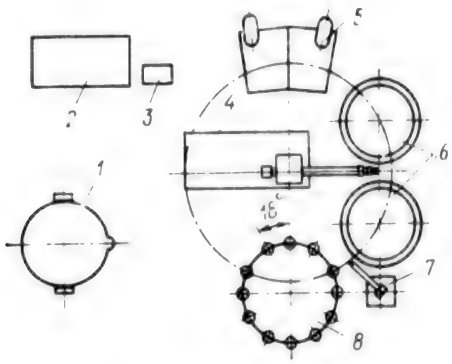

Figure 3.27. Layout of Equipment for Manufacture of Ceramic Shell Molds

Instructions are transmitted after the cushioning layer of all the investment blocks of the platform level to raise the platform for the cushioning layer of the investment blocks of the next platform, and after this job is completed, the storage device is transported for the drying operation and is again returned for application of a second layer of ceramics.

If it is necessary to change the thickness of the applied coating, the robot uses the same or a different compartment of the bath with the suspension and sand cushioning layer according to the corresponding program. The time required to change the control program of the robot and to replace the movable storage platform does not exceed 3 min. The robot is controlled from a console 2, while the production equipment is controlled from console 3. The automated complex includes a hydrolizer 1.

The technological process is based on the use of a metal rack, normalized for a wide range of investment blocks, which permits the use

of a pin-type gripping device of the robot and considerably simplifies the technological cycle of applying the ceramics to investment blocks, different in shape and dimensions. There is no need to reprogram and retool the robot.

Industrial robots are used not only for automation of molding ceramic shells, but also for performing a number of auxiliary operations: loading the crucible stools with molds and placing them into the annealing furnace, loading the smelting-pouring unit with molds and unloading the filled molds, placing the filled molds in the ceramic-removal unit and so on.

The low strength of the investment blocks determines increased requirements on selection of the operating speeds of the manipulation movements of the robot and of its working member. The experience of using universal robots to manufacture ceramic molds showed that, having a specific kinematic redundancy for performing regional movements of the investment block, robots are unable to perform certain functions necessary for the manufacturing process, for example, they have no mechanism for multiple rotation of the wrist (gripping device) at a specific angle with respect to their own axis, which may result in air bubbles occurring in the dead zones of the investment block during application of the suspension by dipping. Adaptation of universal industrial robots to the specific requirements and conditions of the process of molding a ceramic shell requires considerable modification of them and at the same time indicates the exceptional timeliness of developing specialized robots for automation of the given operation.

3.5. Use of Robots and Manipulators for Automation of Finish Operations

Industrial robots are used to automate finish operations for attachment and rotation of the castings during fettling and trimming, and also for cleaning by different methods, completion of loading-unloading and other transport operations, and for checking the quality of the castings are used for automation of finish operations.

Manipulators with remote control of type 99995, having capacity up to 400 kg, are used to separate the elements of the sprue-feed system from the castings. The castings can be fettled by abrasive disks, laser, plasma and acetylene-oxygen burners and so on. A sharp tool is attached to the gripping device of the manipulator. Industrial robots and manipulators are used in similar fashion to automate the operation of trimming the castings.

A diagram of trimming castings using an industrial robot 1, to the wrist of which is attached an abrasive tool 2, is presented in Figure 3.28. The robot moves the tool around the machining surfaces of the casting 3, mounted on a special receiving table, accroding to a given program. The robot should have a minimum of 5 degrees of mobility and should have a long manipulator arm.

A more flexible system of a robotized section for finish machining of castings is presented in Figure 3.29. The industrial robot performs a range of manipulator movements with the castings according to fixed machining positions. The castings are delivered to the robotized complex by a transport conveyer 1 and are placed in special magazines 2 in a strictly oriented position. The robot 8 removes the casting from the magazine and sequentially moves to stationary machine tools to perform cutting operations 3, fettling operations 4 and trimming operations 5, and then places the casting in a container 6 or on a transport device 7.

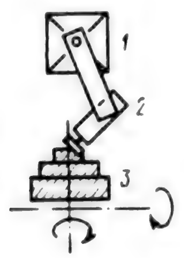

Figure 3.28. Layout for Trimming Castings by Industrial Robot

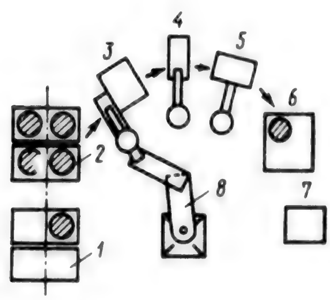

Figure 3.29. Layout of Robotized Section for Finish Machining of Castings

Specialized high-performance industrial robots were used in large-series production for trimming the castings along quite specific surfaces (cylinder block, crankcase, reduction gear housing and so on).

Industrial robots for finish operations should have a control system that moves the working members along a given trajectory, while more flexible control systems should include a microcomputer and microprocessor. Robots with freely programmable control are promising in this layout.

A diagram of an automated complex for machining the surfaces of castings, complicated in configuration, is presented in Figure 3.30. The complex consists of a pendulum manipulator 1 and rotary table 2, to which the casting to be machined is attached. Electronic control permits complex profiles to be machined. Data on those sections of the casting, which must be machined by a grinding disk, are entered in the memory of the control computer.

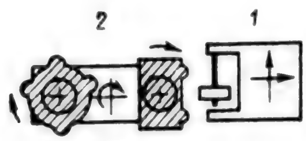

Figure 3.30. Layout for Trimming Castings by Pendulum Manipulator

Industrial robots also permit automation of fettling of castings by the shot blasting and airless shot blasting machining methods. The layout of the robotized complex for fettling of castings 1 in an airless shot-blasting machine 4 with a specialized robot 3 having programmed control, the working member of which is an electromagnetic airless shot-blasting machine 2, operating on the traveling electromagnetic field principle, is shown in Figure 3.31. The shot flying from the shot-blasting machine assumes not only linear but rotary motion as well, which improves the efficiency of fettling the castings.

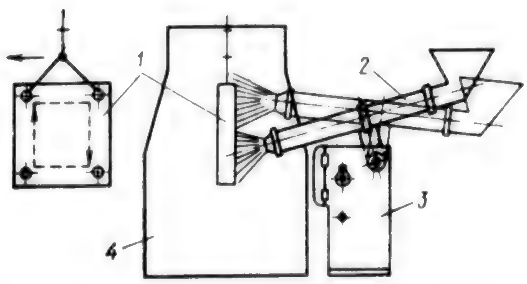

Figure 3.31. Robotized Complex for Airless Shot-Blasting Fettling of Castings

Various types of measuring accessories, equipped with sensors, are used to check the quality of the castings. Industrial robots permit considerable facilitation of this monotonous and fatiguing operation. A robotized complex for checking castings is presented in Figure 3.32. The robot 1 removes the casting from the conveyer 6, which delivers the casting from the cutoff saw 7, and places it in the measuring device 5. The casting is transferred to packaging 4 for assembly of suitable castings if it meets the check standards. Rejected castings are

returned to a container. A safety zone 3 is provided to ensure safe operation of the robot.

Operations for finish machining of castings are the most complicated processes for robotization. Solution of the problem of pattern recognition of the object using hardware and delivery of the object for machining in an oriented position in this field of foundry production leads to the fact that completion of a number of operations in finish machining of castings will be turned over completely to industrial robots in the foreseeable future.

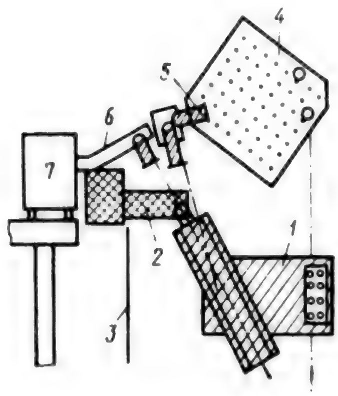

Figure 3.32. Layout of Section for Checking Castings Using Robot

The General Motors Company (United States) has developed a system which uses a computer and video recognition devices for conveyer classification of castings. Studies to develop video recognition devices, which permit broad introduction of robots into disordered industry, a strictly oriented position of the object of which is extremely difficult or impossible, are not being conducted.

Conclusions

Prospects for application of robots and manipulators. The problem of broad introduction of flexible readjustable plants and computer-aided design systems, automatic lines, machines and equipment with built-in microprocessor hardware, robot-engineering, rotary and rotary conveyer complexes is posed in the Basic Directions for the Economic and Social and Development of the USSR for 1986-1990 and for the Period up to 2000.

Robotized production equipment, complexes, and lines are an essentially new type of machines that are capable of rapidly readjusting the technological operating mode with interchangeability of the type of foundry product to be manufactured.

When developing an automation system and flexible automated plants, one should proceed from the necessity of encompassing the entire technological process of casting and one should take into account the prospects of converting to a higher degree of automation of production. Thus, an attempt to conserve today's capital investments through the use of a simpler castings robot remover in automated pressure die casting complexes will not permit in the future complete automation of fettling of castings in a single manufacturing cycle.

Robots with flexible automated foundry production systems will play the role of a linking section between manufacturing modules in all operations of the technological process, transport devices and warehouses, providing for replacement of fittings, tools, loading and unloading raw material, materials, semifinished materials, and finished castings. Flexible automated manufacturing systems permit a 40 percent reduction of the period of product development, a 30 percent increase of the utilization factor of equipment, a 10 percent decrease of the cost of products, and a 30 percent decrease of the labor intensiveness of their manufacture.

Studies on development on manipulators for prepacking the sand and thicknessing the excess in large molding machines, for fabrication of ceramic molds, for removal of groups of castings from containers during lost-wax casting and so on are planned in the USSR. It is also planned to develop a multipurpose manipulator with remote control, designed to remove castings from the knock-out grids, trimming the gates in castings, trimming of castings and manipulation of them, various types of loading-unloading operations, and also of manipulators for coating the cores and priming the castings, transfer of the cores from the machine to a container or to transport devices and so on.

The development of robot engineering is proceeding in the direction of developing machines with maximum capabilities with the least human interference in their activity. Extensive use of precision methods of casting, automated and robotized casting complexes and continuous flow lines, and development of flexible automated manufacturing systems are the most effective directions in development of the technological processes of manufacture of castings.

According to a Decree of the CPSU Central Committee and of the USSR Council of Ministers, dated 11 June 1981, all machines and equipment, work on which is monotonous, injury-hazardous, difficult and harmful to human health, should be equipped with robots, manipulators and other means of mechanization and automation. To implement this decree, the list and technical capabilities of industrial robots must be expanded. As the list of robots in dust- and heat-protection, fire- and explosion-safe versions and of robots capable of operating under extreme and harmful conditions expands, their application in foundry production will also be expanded both in sand casting and in other methods of casting.

Influence of robotization on technology, quality, economic and social aspects. Widescale introduction of robots in industry is an order of time, an objective requirement of the modern phase of scientific and technical progress, a reflection of the growing needs of economics, and a reliable means of increasing and facilitating labor productivity. The use of robots is fundamentally changing the structure of production. The labor of highly skilled adjusters and operators of production equipment, programmers and adjusters of computer hardware and microprocessor technology will replace the hardly effective and low-skilled work of workers and employees. These essentially engineering occupations require a knowledge of mathematics and electronics, physics and electrical engineering, hydraulics and pneumatics, mechanics and electrical equipment. Although robots are also universal machines and means of automation, they service the technological operations of specific production and, therefore, one can not work with them without special technological knowledge.

Introduction of robot engineering in foundry production also permits an increase of the quality of castings and stabilization of the technological process of manufacturing them. It is known that the quality of castings with ordinary methods of production are considerably dependent on the physical condition of the worker, his attitude, feelings and so on. The worker's capacity to sense the course of the manufacturing process changes repeatedly during the shift, which is reflected in the quality of the manufactured product.

Reduced rejection of castings is one of the main aspects of robotization of manufacturing processes. Consideration of all the factors that affect the quality of castings in foundry production is essentially impossible, since they number approximately 2,000. The effect of such a large number of variables that act during the modern manufacturing process of foundry production can be estimated and the corresponding corrections to the course of the process can be introduced only when computer-aided programmed production is used. A robot in foundry production can be regarded as the most universal and fastest means of fulfilling the instructions of the control computer. The experience of using industrial robots confirms their beneficial effect on product quality. A reduction of rejection of castings is the result of eliminating the influence of such individual and subjective factors as skills, experience, worker fatigue, and the physical condition of the worker.

Analysis of modernization and improvement of production, directed toward an increase of labor productivity and an expansion of the volume of produced material benefits, frequently leads to impoverishment of the content of labor, if the problem is solved by traditional means without preliminary social studies at a high level of the aspects of restructuring of industry. A way out of this situation can be found through the use of essentially new engineering and technological solutions, which free man of monotonous, physically difficult operations

that are devoid of intellectual and creative content, having entrusted them to industrial robots and automatic manipulators.

Robots replace man in many cases, making his work faster, with greater accuracy and fewer expenditures, by increasing labor productivity severalfold with steady high quality of the manufactured product. Robots are efficient and advantageous even when the calculation of the economic impact does not yield a high current advantage. But their economic feasibility is manifested very highly if one has in mind the final national economic result and social effect.

The growth of labor productivity in the use of industrial robots is supported by an increase of production skills and by a significant increase in the utilization factor of equipment, since robots do not become tired and can operate 24 hours per day at a steady pace. Only a well developed coordinated control program, reliably operating production equipment, automatic support systems of individual processes and transport devices, timely preventive maintenance and repairs, and support of the work front are necessary for stable operation of a robotized technological process in manufacture of castings. Neither complete darkness nor high temperature nor high dust content and gas pollution of the atmosphere, nor other harmful conditions that are capable of preventing man from working and are hazardous to his health stop the work of an industrial robot. The role of man in a robotized plant is reduced to teaching the robot and checking his work and also to programmable control of the operation of the production equipment, complex, or line. Thus, robotization of production requires development and use of a new generation of production equipment in all sections of the casting process, distinguished by increased productivity, reliability, and efficiency.

However, robotization of production forces a new approach to the requirements of safety. On the one hand, the use of robots ensures an increase of production safety through freeing workers in jobs with harmful, physically difficult and injury-prone conditions. On the other hand, robots can sometimes be sources of increased danger to man and to the production equipment working alongside it, which occurs due to a malfunction of the robot itself, failures in the control system, errors in programming and adjustment, violation of the dynamic operating modes and overloads, due to violation of the interlocking and checking system of manipulation, and losses of the object of transport and due to carelessness on the part of maintenance personnel. Statistics show that a considerable part of accidents to maintenance personnel is related to their being in the work zone during teaching, adjustment and repair of robots. Accidents and injuries are extremely rare during the operation of robots in the automatic mode.

Therefore, robotization of production requires serious attitudes and one should not assume that the robot, even one equipped with an intelligent control system, will operate totally independently and will not require human interference.

Experience shows that introduction of industrial robots in the manufacturing process essentially reduces the turnover of personnel, reduces the number of occupational illnesses, reduces injuries in production and so on.

The introduction of robotized and flexible manufacturing plants should be preceded by an enormous amount of work in the social, technological and engineering spheres of preparation of the manufacturing process. The human factor in solving problems on fundamental restructuring and retooling of foundry production is of primary significance in this regard. The nature of labor itself will change fundamentally--it will become ever more creative, inspiring and interesting.

Continuous technical progress of industrial production results in gradual elimination of the differences in the nature and content of labor in different areas of the national economy. It determines the need for integration of industry, including enterprises of foundry production, highly skilled workers capable of controlling complex production equipment and technical means of automation of production, which include industrial robots and manipulators.

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